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Vol. 1

Data Base for Radioactive Waste Management

ORIGINAL

COMPLETED

Review of Low-Level Radioactive Waste Disposal History

Prepared by J. J. Clancy, D. F. Gray, O. I. Oztunali

Dames and Moore, Inc.

Prepared for
U.S. Nuclear Regulatory
Commission

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Manuscript Completed: August 1981
Date Published: November 1981

Prepared by
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Office of Nuclear Material Safety and Safeguards
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1.0 INTRODUCTION

In this report, a review of previously employed technologies for low-level radioactive waste (LLW) disposal is presented. This review includes an interpretative overview of the history of this technology from its inception during the World War II Manhattan Project to the present. Summaries are provided of the geology, hydrology, meteorology, climate, and operations of six commercial disposal sites as well as five major and several other smaller government disposal sites.

In Section 2.0 of this report, a brief background and overview of LLW disposal practices is presented. Summaries of the characteristics and histories of the six existing commercial sites are presented in Section 3.0, while summaries of the characteristics and histories of the five major and several minor U. S. Department of Energy (DOE) disposal sites are presented in Section 4.0.

Each of the site summaries begin with an introduction, followed by a brief description of site environmental characteristics. This is followed by a section on disposal experience consisting of a brief discussion of site disposal practices and a description of any problems encountered. An interpretative discussion on the site follows. This discussion includes the authors' opinions and analyses of the likely causes of positive or negative aspects of site performance experience.

Following these individual site summaries, a summary and discussion of the lessons learned from past disposal history is presented in Chapter 5.0. A summary of the volumes and gross activities of wastes disposed at the commercial and government sites is presented in Appendix A.

2.0 BACKGROUND

The beginning of the "atomic" age is often linked to the Manhattan Engineering District Project during World War II. The bulk of the work on this project was performed under great secrecy in government-owned facilities. When various waste materials were generated within these laboratories, reactors, and processing plants, it was necessary to employ a disposal practice which was safe, convenient, and secure. Thus, the first disposal locations chosen were generally in close proximity to the point of generation.

The concept of shallow land burial was adopted for several reasons. First, it could be accomplished quickly and with relative ease using conventional construction equipment. Second, for waste materials which exhibited significant external radiation, shallow land burial provided some shielding attributes. Shielding would be provided to some extent as soon as the waste was lowered into a trench, pit, or shaft. Third, the methodology was attractive because it was a modification of an existing waste management practice -- i.e., sanitary landfill disposal. Fourth, soil scientists knew as early as the 1940's that certain chemical properties of soils could be used advantageously in shallow-land burial. In certain soils, the retention capability of soil minerals could enhance the performance of a disposal site by delaying the movement of radionuclides through soil.

In addition to the security and economic advantages of locating disposal sites in close proximity to sources generating the waste, minimizing low-level waste transport also offered other positive benefits. Waste disposal at or near the point of generation generally eliminated the need for shipping wastes by public transportation systems. In general, the fewer the miles required for transportation, the lower the likelihood of transport accidents. (A rationale similar to the above was applied during the establishment of the commercial disposal sites in the early 1960's.)

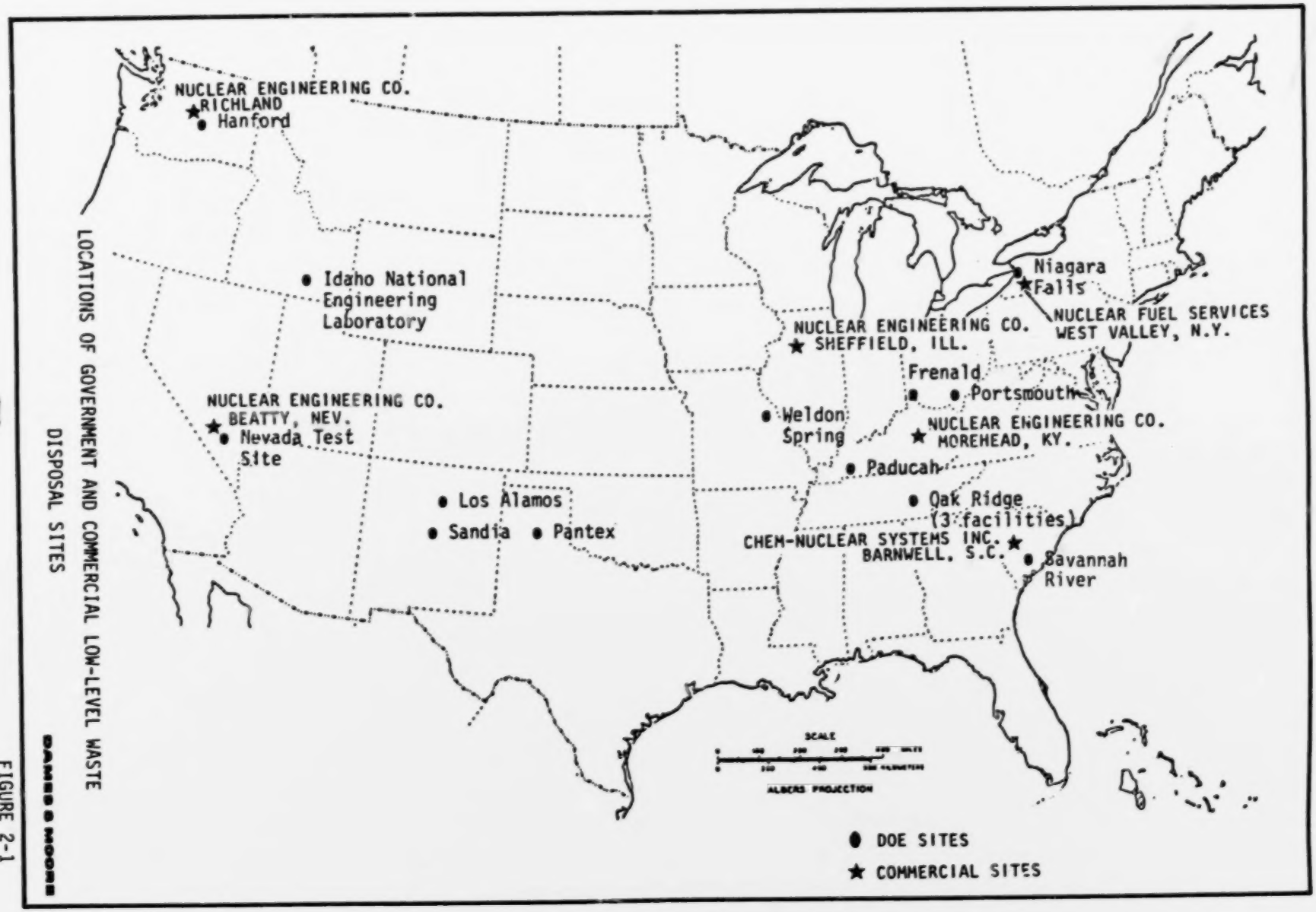
Five large government facilities were eventually constructed which generated significant volumes of waste. These facilities include Oak Ridge National Laboratory (ORNL), Los Alamos Scientific Laboratory (LASL), Hanford Reservation (HR), Savannah River Plant (SRP), and Idaho National Engineering Laboratory (INEL). Activities at ORNL, LASL, and HR (which contained the first federal LLW disposal sites) gained full momentum in 1943. In 1949, the two remaining large defense facilities, SRP and INEL, were opened.

In addition to these five major facilities, a number of other government installations have also generated and disposed smaller volumes of waste on site. These facilities include the Nevada Test Site, the Pantex Plant (Texas), Sandia Laboratory (New Mexico), the Paducah Gaseous Diffusion Plant (Kentucky), the Feed Materials Production Center (Ohio), the Portsmouth Gaseous Diffusion Plant (Ohio), the Weldon Spring Site (Missouri), Lawrence Livermore Laboratories (California), the National Lead Company (New York), Brookhaven National Laboratory (New York), and the Oak Ridge Y-12 and K-25 facilities (Oak Ridge, Tennessee).

The locations of the five major and several other government disposal sites are shown in Figure 2.1.

Several currently-operating U.S. Department of Energy (DOE) facilities which generate LLW do not dispose of it within their site boundaries, and must transport their LLW to other DOE sites. These DOE facilities include Mound Facility (Ohio), Argonne National Laboratory (Illinois), Bettis Atomic Power Laboratory (Pennsylvania), Lawrence Livermore Laboratory (California), the Rocky Flats Weapons Plant (Colorado), and other facilities within the eight operational regions of the DOE.

The early volumes of waste generated and disposed at the government facilities are unknown due to the nature of the projects generating



LOCATIONS OF GOVERNMENT AND COMMERCIAL LOW-LEVEL WASTE DISPOSAL SITES

FIGURE 2-1

the wastes and the secrecy they required. However, it is known that currently over 86,300 m^3 (three million ft^3) of LLW are generated annually at the government sites. (A summary of the volumes of wastes generated and stored at DOE sites is presented in Appendix A.) It is estimated that a large portion of this volume of DOE wastes (perhaps as high as 50% in some years) may be "suspect" waste such as paper trash from a research laboratory which could contain radioactivity.

The types of waste disposed at the federal sites primarily include contaminated trash, process waste, contaminated equipment and materials, and activated metals. The contaminated trash consists of protective clothing (e.g., gloves and laboratory coats), paper trash, packing material, broken glassware, tubing, plastic sheeting, and animal carcasses. Contaminated equipment contains such items as gloveboxes, drain traps, ventilation ducts, shielding, and laboratory equipment. Process waste comprises filter cartridges, filter sludges, spent ion-exchange resins, and evaporator bottoms.

The LLW disposed at the DOE sites is packaged in a variety of containers. Waste containing only small quantities of radioactivity is packaged in plastic bags, metal cans, cardboard boxes, wooden boxes, and carbon steel drums. Tritium wastes may be packaged in asphalt lined or covered containers. Wastes containing intermediate and high quantities of radioactivity are frequently packaged in concrete or metal containers. For higher activity wastes, the package may be designed to provide both biological shielding and some measure of containment following disposal.

The expansion of the peaceful use of radioactive materials during the latter part of the 1950's resulted in the first significant quantities of commercially-generated LLW. Low-level waste was generated from the use of radioactive materials in medicine, research, and from commercial generation of nuclear power. Most of the private industry radioactive material licensees used commercial ocean disposal

contractor services (then seven firms) to dispose of their waste at a few AEC-approved* off-shore disposal sites. As a result of several decisions relating to the economics and potential difficulties (e.g., monitoring) of ocean disposal, land disposal of commercially-generated waste was increasingly encouraged by the AEC.

The AEC decided that considering the time for proper hydrogeologic pre-operational investigations, it might be prudent to establish "interim" disposal sites for commercial LLW. Strong emphasis was placed on the temporary use of the federal disposal sites since it was believed that the sites would be rapidly filled if used by both federal and commercial waste generators. In 1960, two sites (INEL and ORNL) were thus designated. These disposal sites were employed for this purpose until 1963, the first full year of commercial disposal site operation. Thereafter, AEC- and ERDA-generated waste was frequently shipped to the commercial sites (for economic reasons and also to help promote their use). In 1979, commercial disposal site capacity reached a premium and the use of commercial sites for most government-generated waste was discontinued.

The first commercial disposal site was opened in 1962 at Beatty, Nevada by the Nuclear Engineering Company (NECO). Later the same year, a disposal site was opened by NECO in eastern Kentucky on a ridge known as Maxey Flats. In late 1963, a disposal site was opened on the property of a nuclear fuel reprocessing plant operated by Nuclear Fuel Services and located near West Valley, New York. In 1964, a disposal site was opened by California Nuclear, Inc. within

---

* The U. S. Atomic Energy Commission (AEC) was originally charged with the responsibility of both regulating industry and performing research and development work on new or improved uses of radioactive materials. In 1975, the AEC was split into two newly-created Federal agencies. The regulatory role was taken over by the U. S. Nuclear Regulatory Commission (NRC). Other AEC activities were carried out by the U. S. Energy Research and Development Administration (ERDA), which became and is presently the U. S. Department of Energy.

the Hanford Reservation near Richland, Washington. California Nuclear later (1967) opened the fifth commercial disposal site near Sheffield, Illinois. (Both the Richland and the Sheffield sites were subsequently acquired and operated by NECO, since renamed U.S. Ecology, Inc.) Finally, in 1971, Chem-Nuclear Systems, Inc. (CNSI) opened the LLW disposal site near Barnwell, South Carolina. The locations of these sites are depicted in Figure 2-1.

The annual LLW disposal rates from the first full year of commercial site operation (1963) through 1980 are summarized in Appendix A. During 1963, a total of 6,241 m^3 (220,400 ft^3) of LLW was buried at the Beatty, Maxey Flats, and West Valley sites. By 1975, when all six sites were in operation, the annual level of waste disposed had risen to 57,310 m^3 (2,073,600 ft^3). Since then, however, disposal operations at three of the six licensed disposal sites has ceased (Sheffield, Maxey Flats, and West Valley). By 1979, the disposal rate had risen to over 85,000 m^3 (3 million ft^3) per year, but there were only three sites available: Beatty, Richland, and Barnwell. Two of the three remaining commercial sites were temporarily shut down in 1979 (Beatty and Richland) for reasons unrelated to the long-term performance capabilities of the sites. Currently, all three sites (Beatty, Richland, and Barnwell) are open, however,the Barnwell facility has annual disposal volume restrictions.

The wastes disposed at the commercial sites are similar in physical characteristics to that disposed of at DOE sites, but are predominantly from nuclear fuel cycle, medical and institutional, and industrial sources. Details of the physical, chemical, and radiological characteristics of these wastes, and projections of volumes and radiological characteristics are considered in Volume 2 of this series of reports.[1]

A summary of site characteristics at the six commercial and five major government LLW disposal areas, which are considered in more detail in Chapters 3 and 4, is presented in Table 2-1.

TABLE 2-1 . Summary of Site Characteristics

	Mean Annual Precipitation (mm)	Surface Material	Interstitial Permeability	Bedrock Material	Depth to Groundwater (m)	Depth to Regional Aquifer (m)	Surface Water Proximity (km)	Flow Characteristics	Adsorptive Capacity of Surface Material
Government Sites									
LASL	465	Weathered Tuff	Moderate	Volcanic Tuff	200-400	200-400	1	Small Ephemeral	High
INEL	218	Alluvial Sand-gravel	Moderate	Basalt	180	180	3.2	Small Ephemeral	Moderate
ORNL	1,400	Weathered Shale	Very Low	Shale, Limestone	20	None Present	On-Site	Small Perennial	High
HR	180	Clay, Sand, Gravel	Moderate to High	Basalt	100	100	10	Large Perennial	Moderate
SRP	1,190	Sand, Sandy Clay	Low	Clay, Sand, Sandstone	10-20	200	1	Small Perennial	Moderate
Commercial Sites									
Beatty	65-127	Clay, Silt, Sand, Gravel	Moderate to Low	Metamorphic, Sedimentary, Volcanic	99	99	16	Small Perennial	Moderate
Maxey Flats	1,092-1,194	Clay, Weathered-Siltstone and Stone	Low	Clay-Shale, Siltstone Sandstone	Unknown	84		Small Perennial	Moderate to High
West Valley	1,041	Weathered Till-silty clay and gravel	Low	Shale, Siltstone	31-38	>60		Small Perennial	High
Richland	159	Clay, Sand, Gravel	Moderate to High	Basalt	67	67	11	Large Perennial	Moderate
Sheffield	891	Silt Sand, Clay	Low	Shale, Limestone	6-15	>50	On-Site	Small Ephemeral	Moderate
Barnwell	1,190	Sand-Clay	Low	Sedimentary-Sand	10-20	200	1	Small Ephemeral	Moderate

REFERENCES FOR CHAPTER 2

(1) Wild, R. E., et. al., "Data Base for Radioactive Waste Management, Volume 2. Waste Source Options Report," NUREG/CR-1759, Dames and Moore for U. S. NRC, November 1981.

3.0 COMMERCIAL DISPOSAL SITES

At one time six commercial disposal facilities served utilities, hospitals, research facilities, industries, and some government nuclear facilities, for shallow land burial of low-level radioactive waste (LLW). These six facilities include those located near: (1) Maxey Flats, Kentucky, (2) West Valley, New York, (3) Sheffield, Illinois, (4) Barnwell, South Carolina, (5) Richland, Washington, and (6) Beatty, Nevada. The accumulated volumes, land area, and current status of the sites are summarized in Table 3-1.[1]

At the present time only three of these sites are still open to accept LLW for disposal. Two of the open disposal sites are in the Western United States, although most radioactive waste is generated east of the Mississippi River. In 1979 the only eastern disposal site now open (Barnwell) disposed about 75% of the commercially-generated waste. The histories and environmental settings of these six sites are reviewed in the following sections.

3.1 Maxey Flats, Kentucky

The Maxey Flats disposal facility is sited on a flat-topped ridge known as Maxey Flats in Fleming County, Kentucky. Site vicinity is shown in Figure 3-1. The site covers 102 ha (252 acres) of land, although only about 17 ha (42 acres) is designated as a restricted area (that is, an area having restricted access and controlled by the licensee for purposes of radiation protection). Within the restricted area, which is shown in Figure 3-2, between 10 to 11 ha (24 to 27 acres) has been used for disposal of waste into trenches, pits, and hot wells.[2]

The site is owned by the Commonwealth of Kentucky and is licensed by the Kentucky Department for Human Resources (KDHR). The site was opened in early 1963 by the Nuclear Engineering Company (NECO), now U. S. Ecology (USE), who held the lease for the site until 1978.

TABLE 3-1 . Summary of Status of Commercial Disposal Sites

Site	Licensed Land Area (Hectares)	Volume of Waste Disposed Through 1980 in m^3 (ft^3)	Year Opened	Current Status
Beatty, Nevada	32	90,116 (3,182,000)	1962	Open
Maxey Flats, Kentucky	103	135,089 (4,770,000)	1963	Closed in 1978
West Valley, New York	10	66,837 (2,360,000)	1963	Closed in 1975
Richland, Washington	40.5	61,739 (2,180,000)	1965	Open
Sheffield, Illinois	8.1	90,513 (3,196,000)	1967	Filled to Capacity in 1978
Barnwell, South Carolina	105	323,563 (11,425,000)	1971	Open with annual disposal volume restriction

Source: Reference 1.

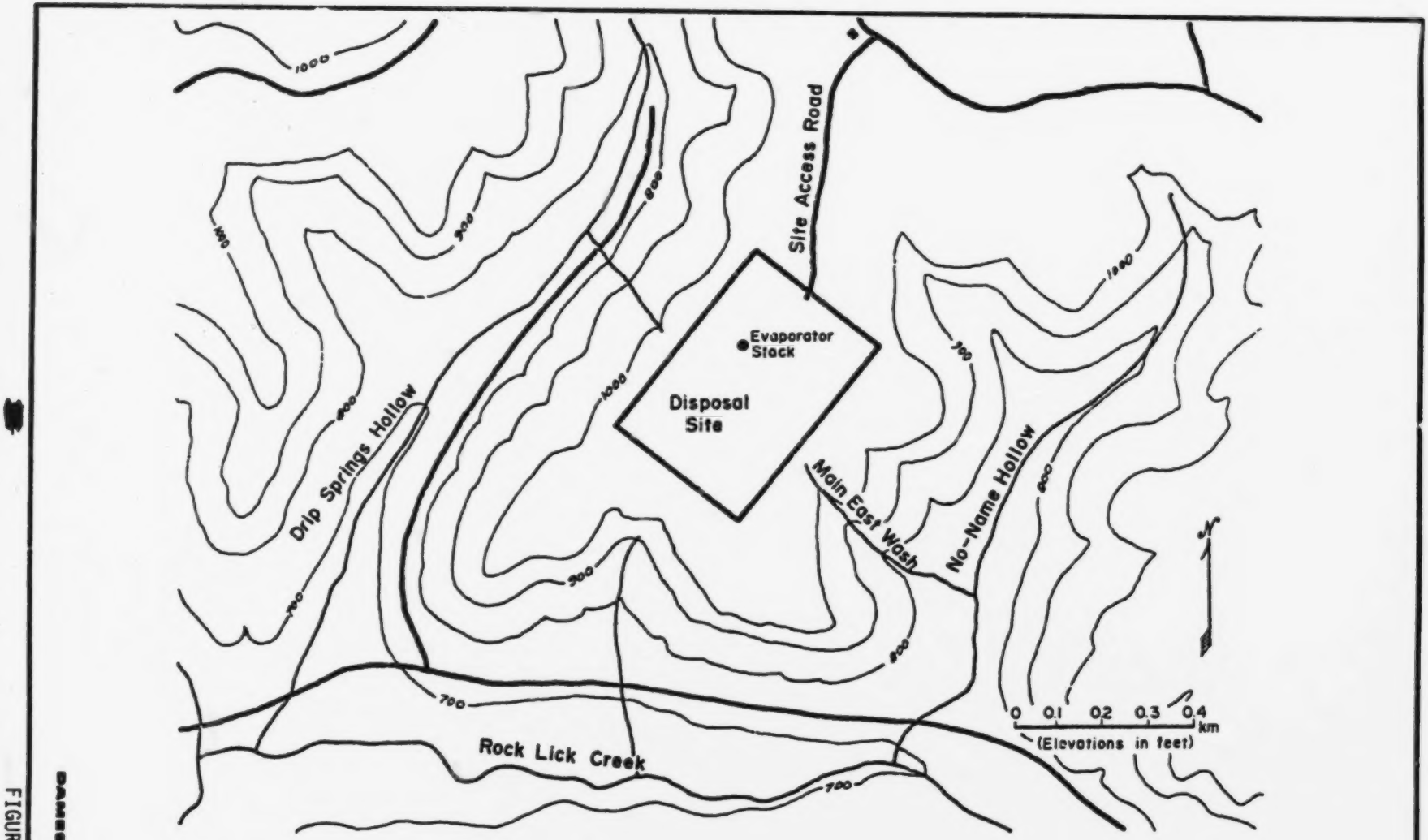


FIGURE 3-1

VICINITY OF MAXEY FLATS SITE

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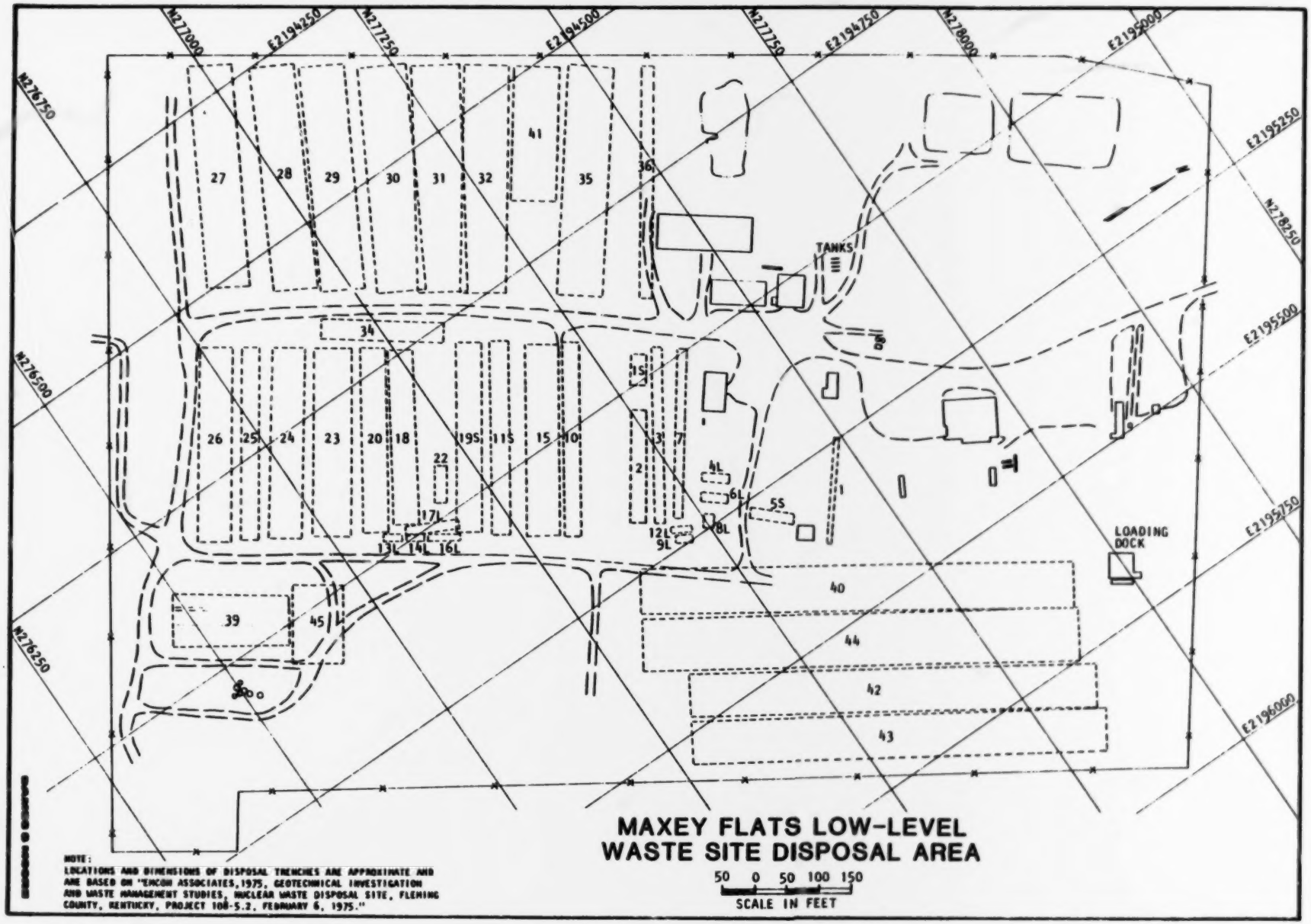
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18
19S
11S
15
10
3
2
1
4L
6L
8L
12L
9L
55
17L
13L
14L
16L
39
45
40
44
42
43
TANKS
LOADING DOCK
MAXEY FLATS LOW-LEVEL
WASTE SITE DISPOSAL AREA
50 0 50 100 150
SCALE IN FEET
NOTE:
LOCATIONS AND DIMENSIONS OF DISPOSAL TRENCHES ARE APPROXIMATE AND ARE BASED ON "ENCOH ASSOCIATES, 1975, GEOTECHNICAL INVESTIGATION AND WASTE MANAGEMENT STUDIES, NUCLEAR WASTE DISPOSAL SITE, FLEMING COUNTY, KENTUCKY, PROJECT 108-5.2, FEBRUARY 6, 1975."

FIGURE 3-2

In June 1978, however, the Commonwealth of Kentucky signed an agreement with NECO to buy back the lease rights for the site. Since then, the license for the site has been held by another Commonwealth agency, the Kentucky Department for Natural Resources and Environmental Protection (KDNREP).

The KDNREP is actively involved in ensuring continued protection of the health and safety of the public, and in placing the site in a caretaker status. The site has since June 1981 been maintained for KDNREP and the site liquid treatment facility (an evaporator) operated by Hittman Nuclear and Development Corporation, Inc., a custodial contractor to the Commonwealth. Earlier, National Waste Management Services, Inc. performed these services, having assumed these responsibilities in 1979 upon NECO's departure.

3.1.1 Site Environmental Characteristics

The subsurface geology of the site is representative of the eastern flank of the Cincinnati Arch, and consists of gently dipping sedimentary rocks of Silurian, Devonian, and Mississippian Age. These sedimentary rocks generally consist of clay-shale, siltstone, fine grained sandstone, and fissile carbonaceous shale.[3]

Disposal trenches and pits are located within the weathered surface soils and the Nancy Member of the Borden Formation which consists predominantly of a poorly fissile, dark blue to greenish shale interbedded with lenses of fine grained sandstone and siltstone. The clayey cover soils range in depth from 0.3 to 3 m (1 to 10 ft) and are residual soils formed from in-situ weathering of the underlying shales and siltstones.

The highly weathered and slightly weathered sections of the Nancy Member are often separated by a hard siltstone or sandstone bed. The least weathered portions of the Nancy appear to have low primary effective porosity and consequently low permeability. However, a greater permeability may be present locally because of the presence of

secondary openings (nearly vertical joints). Structural features of major significance (e.g. faults) have not been identified in the immediate vicinity of the site.[3-6]

The climate is humid continental characterized by warm, humid summers and cold winters. The mean annual precipitation ranges from about 1092 to 1194 mm (43 to 47 in). The driest months are usually during late summer and autumn; the wettest months are usually during spring and early summer.[2]

Hydrogeologic properties of the various sedimentary rock layers underneath the site appear to be variable. The primary permeability (determined by laboratory analysis) of the Nancy Member, due to intergranular spaces and interconnections, is approximately 10^{-8} to 10^{-10} cm/sec.[5] The secondary permeability (due to joints and fractures) has been estimated by field experiments at a few locations to be approximately 10^{-7} cm/sec or greater. However, considerable uncertainty exists concerning the location, distribution, and overall hydrogeologic significance of these secondary openings. The storage capacity of these formations is generally low. The closest surface water body is Rock Lick Creek, which runs through the valley immediately below the site. This stream has an average discharge of approximately 0.2 m^3/sec (7 cfs).[2,5]

The interaction of the surface water regime with the local groundwater regimes has not been accurately determined. However, preliminary investigations indicate that there are several perched water layers of unknown lateral extent, with a lower water table located about 84 m (275 ft) below the site surface within the Ohio Shale Formation.[2,5]

Wells and cisterns drilled into the groundwater regimes receiving direct infiltration and/or seepage through the weathered surface layer generally yield very minor quantities of water and these regimes are

therefore used to only a small extent.[2] In the material near the ground surface disturbed by excavation (within the top 10 m), some horizontal groundwater movement between disposal trenches has been observed. This groundwater movement between trenches is probably along fractures which have been augmented by excavation and construction activities.[5,6]

3.1.2 Disposal Experience

Background

The volume of waste disposed at Maxey Flats between 1963 and 1978 totals about 135,089 m^3 (4,770,000 ft^3). This volume of waste has been estimated to contain over 2.4 million curies of byproduct material, over 241,769 kg (533,000 lbs) of source material, 431.6 kg (952 lbs) of special nuclear material, and 63.76 kg (140 lbs) of plutonium. (See Appendix A for definitions of source byproduct and special nuclear material.) Included in the disposed byproduct material is over 16,000 Ci of material identified only as mixed fission products and 190,000 Ci of other material not specifically identified as to radionuclide content. The majority of the waste received was in solid form except for about 2.2 million liters of liquid waste which was received and solidified in urea-formaldehyde prior to disposal at the site.[2,7,8]

Low-activity wastes disposed of at Maxey Flats included miscellaneous materials such as paper, trash, clothing, protective apparel, laboratory glassware, obsolete equipment, duct work, radiopharmaceuticals, waste plastic, tubing and miscellaneous rubble. Higher activity wastes included solidified liquids shielding accessories (glove boxes), filters, ion-exchange resins, activated metals, and evaporator sludges. Transuranic waste can be found in glove boxes, rubber tubing, gaskets, plastic, paper, and rags, paper and rags are estimated to contain as much as 50% of the transuranics.[8] The majority

of the wastes were contained in steel drums; other packagings included wooden and cardboard boxes. The principal organic input to the disposal areas included animal tissue matter, animal carcasses, paper, cardboard, wood, plastics, and organic chemicals.[7-9]

The waste has been disposed in over 40 trenches, numerous hot wells (source wells), and several special pits. The trenches were generally unlined, with dimensions ranging from 46 to 207 m (150 to 680 ft) in length, 3 to 22 m (10 to 75 ft) in width, and 2.7 to 9 m (9 to 30 ft) in depth.[2]

The site license required the floors of the trenches to slope at least one degree, with a sump constructed at the low end for dewatering purposes. Initial requirements called for the installation of gravel drains but this requirement was later dropped because difficulties apparently arose with fine particulates clogging the drain. It was also believed that the trench contents provided ample void space to carry the leachate to the sumps.[10] The trenches have been backfilled with a minimum of one meter of excavated soil to assure that a radiation level of 2 mR/hr at the surface of the trench is not exceeded. Additional backfill was mounded over the required 1 m (3.3 ft) of soil and then compacted. Shallow rooted vegetation was then planted to prevent erosion.[10]

The hot wells are lined with steel pipe, concrete or tile and are generally 4.6 m (15 ft) deep by 0.6 to 1.0 m (1.9 to 3.2 ft) in diameter. The hot wells are usually capped with concrete at each end. Usually high specific activity gamma sources, a potential exposure hazard to operating personnel, were disposed of in these wells. Large volume, higher activity waste such as spent resins from power reactors were disposed of in several pits. These pits have dimensions that range from 4.6 to 22.9 m (15 to 75 ft) in length, 2.7 to 7.6 m (9 to 25 ft) in width, and 1.5 to 4.6 m (5 to 15 ft) in depth.[10]

Problems Encountered

In the early 1970's, the Commonwealth of Kentucky became concerned about the accumulation of water in completed trenches at the site and the increase in the volume and activity of waste being received at the site for disposal. The Commonwealth of Kentucky required the Maxey Flats site operator to institute a water management program at the site which included pumping water from trenches to above-ground storage tanks and installing an evaporator to concentrate the pumped liquids for disposal as solids. The pumping program commensed in 1972, and the evaporator was installed in 1973. This leachate pumping and evaporation program has continued to this day. As shown in Table 3-3, the leachate is contaminated with a variety of radionuclides, particularly tritium.(11)

In October 1974, the State of Kentucky informed NRC of the results of their special six-month environmental study at Maxey Flats.(12) The study, published in December 1974, concluded that the disposal site was contributing radioactivity to the local environment, but at levels which did not present a public health hazard. The study identified ^{3}H, ^{60}Co, ^{89}Sr, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{238}Pu, and ^{239}Pu in individual samples in the unrestricted environment. The radionuclide concentrations ranged from slightly to several orders of magnitude (for certain individual samples) above concentrations that were defined as ambient and considered significant for purposes of the study.(12)

The Commonwealth of Kentucky then recommended further studies at the site to assess the long range health and safety significance of their findings. Since that time, numerous studies have been carried out by the Commonwealth, Commonwealth contractors, NRC, USGS, and DOE to determine the extent of pathways and to better understand the characteristics of the site. As part of these studies, it was determined that there were four potential routes for the release of radioactivity from the site:(2)

TABLE 3-2 . Summary of Brookhaven National Laboratory (BNL) Results of Radiochemical Analysis of Trench Leachate*

Analysis	Range (pCi/l)
Gross Alpha	140 - 640,000
Gross Beta	1,500 - 57,000,000
Gross Gamma	<10 - 16,000 cpm**
Tritium	250,000 - 7,400,000,000
Sodium-22	23 - 130
Manganese-54	170 - 190,000
Cobalt-60	19 - 840,000
Strontium-90	1900 - 9,900,000
Cesium-134	<100 - 22,000
Cesium-137	<20 - 170,000
Plutonium-238	<2 - 126,000
Plutonium-239/240	<1 - 21,000
Americum-241	<20 - 28,000

* Source: Reference 11.

** cpm : counts per minute

- o Surface water runoff;
- o Atmospheric fallout from the evaporator;
- o Lateral movement from trenches through the soil zone; and
- o Movement from the trenches through fractures in surrounding rocks.

Of these, the first two routes are believed to contribute the major portion of the off-site releases. The extent of occurance of the latter two possible routes as well as the relative contribution of each possible route has not yet been completely determined.

In April 1975, the Governor of Kentucky requested NRC to independently assess conditions at the Maxey Flats site and to provide him with findings and recommendations. An NRC review group was appointed and reviewed information about the site, conducted a site visit and met with Kentucky and NECO officials. NRC concluded, on the basis of their study, that there is no significant public health problem associated with the release of radioactive material from the disposal site and that Kentucky had taken appropriate action to implement the recommendations made in their December 1974 report.[13,14] A number of other investigators have also subsequently concluded that there is no significant public health and safety problem associated with the site releases.[15-17]

NRC also made several recommendations concerning methods to improve the water management program and to minimize the potential for migration of radioactivity. In response to NRC's recommendations, Kentucky required the site operator to continue to remove water from trenches to minimize the potential for migration of radioactivity and to bring and maintain the trenches in a dry status. Water collecting in the trenches was seen to principally result from infiltration rather than from groundwater movement. Improvements in operations undertaken at the site to reduce the likelihood of water contacting the buried waste have included grading and improving surface drainage, recapping older

trenches to reduce cap permeability, improving procedures for capping new trenches, establishing a vegetation cover over completed trenches, eliminating non-engineered on-site ponds, installing additional sumps in new trenches to facilitate water removal, routine backfilling of waste as it was placed in the trenches, and removing precipitation from trenches as the trenches were being filled. These efforts, plus the removal of several areas of surface contamination, were effective in reducing the release of radioactivity from the site, and radioactivity levels detectable in the off-site environment decreased.[14]

An EPA press release in January 1976 focused a great deal of public attention on shallow land disposal. The press release concerned an EPA report[18] which presented environmental data developed during Kentucky's six-month study, described various potential migration pathways, and drew conclusions from EPA's analysis of the Kentucky data. The EPA report was reviewed by the NRC, the Commonwealth of Kentucky, and others, and comments provided to EPA. NRC commented that the report failed to give adequate attention to the public health and safety significance of the data and that the paper was preliminary in nature since it presented several conclusions concerning pathways for migration of plutonium based on data which the author conceded equally supported other possibilities. The Commonwealth of Kentucky viewed the report as not being adequately objective.[14]

The Kentucky Legislature subsequently imposed a 10 cents per pound excise tax on waste received at the site for disposal, effective in June 1976. The tax was intended to assure that adequate funds for any contingency were available. Prices at other disposal sites were primarily determined on a cubic foot basis and ranged from $\$1.25/ft^3$ to $\$3.25/ft^3$ for most categories of waste. The additional tax in Kentucky resulted in a disposal cost that was 3 or 4 times higher than the charges at the other sites, and the Maxey Flats site was consequently virtually unused during the second half of 1976 and through 1977.[14]

The volume of waste that did get shipped to Maxey Flats after imposition of the excise tax was generally of high specific activity. The average concentration of radioactivity in the waste disposed at Maxey Flats in 1975 and 1976 was about 17.0 Ci/m^3 (0.48 Ci/ft^3). In contrast the average activity concentration of waste disposed in 1977, the first full year following imposition of the excise tax, was 1197 Ci/m^3 (33.8 Ci/ft^3), or 67 times the previous average. (See Appendix A for volumes and concentrations.) During 1976 and 1977, many shipments included reactor core components and other high activity items.

The site was closed on December 27, 1977. Following negotiations with the site operator, Kentucky signed an agreement with NECO in May 1978 whereby the lease rights to the site were bought back by the State. A one year contract between the State and NECO for water management (including evaporator operation) and site maintenance was instituted at this point. When this contract expired, a new custodial contractor was brought in to perform these services.

Since the installation of the evaporator in 1973, over 25 million liters of contaminated liquids have been processed, creating over 681,000 liters (180,000 gal) of evaporator concentrates (bottoms). The concentrated bottoms are stored in several on-site steel storage tanks and will be eventually solidified. The contaminated liquids have included trench leachate as well as lower activity contaminated liquids currently stored in two on-site ponds. In the past, the evaporator processing rate was below the annual leachate production rate, which has been estimated to be currently between 2.13 and 2.17 million liters per year (575,000 - 600,000 gal/yr).[11] More recently, the evaporator processing rate has been about 4.9 million liters per year (1.3 million gal/year).

The financial burden to the Commonwealth of Kentucky to maintain this site is considerable. The annual cost of maintenance which includes

trench cap and general maintenance, leachate pumping, and leachate treatment is over $700,000. This cost includes costs of about $400,000 per year for the custodial contract and over $300,000 per year for expendables and supplies. The custodial contract covers administration, maintenance of the site, leachate pumping, and evaporator (treatment) operation. The annual expendables include large propane costs (to fuel the evaporator) and other miscellaneous expenditures (e.g., drainage repair).

For the fiscal biennium commencing July 1, 1980, the licensee of the site, the Kentucky Department for Natural Resources and Environmental Protection, requested $3.12 million dollars to cover routine maintenance leachate treatment and pumping, and capital construction (e.g., trench cover improvements). This request was approved by the Appropriations and Revenue Committee of the Kentucky Legislature at a reduced funding level.[19]

Additional funds will be required to solidify the accumulated evaporator concentrates, to dispose of the solidified material, and to stabilize the site to further reduce accumulation of contaminated leachate.

3.1.3 Discussion

The difficulties experienced at the Maxey Flats site are believed to have been brought about by a number of interrelated factors, including site characteristics, waste form, site design and operation, and institutional considerations. Although the difficulties have not caused significant off-site releases or significant off-site exposures, they have resulted in considerable expenditures of money by the Commonwealth of Kentucky to maintain the site in a safe condition. These expenditures were neither planned for nor funded for while the disposal facility was operating. They have also resulted in difficulties in predicting the levels of future impacts or required maintenance.

Siting factors contributing to the difficulties included a very humid environment (44 inches of rain per year) coupled with a complex site geology. The low permeability of most of the site soils, along with the humid environment and site operational practices, has resulted in a water accumulation problem (the "bathtub" effect) in many of the disposal trenches.

In addition, numerous fractured formations exist in the subsurface media. Some investigations on these fractured formations have been performed.[5] In general, however, the locations and extent of fractured formations cannot be ascertained, and they raise the possibility of subsurface migration of radionuclides. Consequently, they significantly increase the difficulty of predicting the long term performance of the site.

The waste form has probably been one of the more significant factors leading to the current difficulties. Most of the waste that was disposed into the site is believed to have been either composed of very easily degradable material or packaged so that large void spaces existed within the waste or between the waste and the packaging. Frequently, these easily degradable waste streams contained little or no radioactivity. Some of the waste packages (such as cardboard and fiberboard boxes) were often easily degradable. The wastes often contained chemical agents that helped to further increase waste degredation and leaching of radionuclides.

As the waste material degrades and compresses, a process which is accelerated by contact by water, additional voids are produced. This leads to settlement of the disposal trench contents, followed by subsidence or slumping of the disposal trench covers. This increases the percolation of water into the disposal trenches, accelerating the cycle. This slumping and subsidence is frequently quite sudden.

Initially, much of this slumping would be expected to be caused by compression of the wastes packaged in weak or easily degradable

containers. Over the short term, longer lasting but still degradable rigid containers such as wooden boxes, 55-gallon drums, and steel liners would be expected to help reduce subsidence. The rigid containers initially provide some structural support to the trench covers, and act to "bridge" voids within the disposal trench and waste packagees. Eventually, however, this structural support is lost as the rigid containers rust or rot out, leading to disposal trench settling at rates which are difficult to predict. Such settling (and site maintenance activities) can continue for long time periods.

As mentioned above, site design and operating practices are believed to have also contributed significantly to the rapid waste degredation, subsequent slumping of the trench covers, and influx of precipitation. The waste was emplaced within the disposal trenches with little or no attempt to segregate wastes according to characteristics such as chemical content or the relative stability of the waste packages. In general, little compaction was given to the disposed waste, backfill, and trench covers other than that provided by driving over the disposal trenches with heavy trucks. Given all these factors, considerable void spaces are believed to have existed within the trenches which promoted rapid settling. Another factor was that water was frequently allowed to stand in the disposal trenches while being actively filled. This again helped to promote rapid waste degredation and settling.

Other design and operational factors which are believed to have contributed to the observed problems involved the manner in which many of the disposal trenches were constructed. The trenches were more or less dug as needed, following no fixed pattern. The locations of the trenches were inadequately surveyed so that there is currently uncertainty regarding the dimensions and outlines (surface coordinates) of some of the trenches. Observations have been made of trenches characterized by meandering walls and depressions in the trench floors. The latter, of course, would tend to collect standing water and reduce the ability to drain liquids to trench sumps where the

liquid may be removed. In addition, the trenches were occasionally constructed so close together that localized slumping of one trench wall would occasionally expose the contents of the adjacent trench. These occurances, plus the fractured formations discussed above, have resulted in a situation such that several of the disposal trenches are hydrologically connected to one another.

Another operational problem was non-uniform practices in handling radioactive material. These variable handling practices has led to several incidences of contamination of site grounds and equipment. This spread of contamination was caused by small leaks and spills from packaged wastes delivered to the site, and was also associated with a liquid solidification operation carried out on site. In this solidification operation, bulk shipments of low activity liquids were delivered to the site for solidification in urea-formaldehyde prior to disposal. Another contributor to the surface contamination (quite possibly the most significant) has been the deposition from the evaporator operation.

This contamination of the site surface has led to a number of problems. In addition to additional exposures to site personnel, some of the contamination has probably been transported off-site by wind or surface water runoff. Of more long-term concern, the site surface contamination has complicated assessment of the relative contribution of each of the possible routes of radioactivity released from the site, and consequently may have reduced the effectiveness of the environmental monitoring program at the site. This situation naturally affects identifying and implementing measures to reduce off-site releases, as well as complicates predictions of long-term site performance.

The lack of sufficient long-term institutional and regulatory considerations have probably had one of the greatest effects on site performance. These institutional considerations have principally

involved insufficient planning for site closure, funding for closure and for long-term care, and appreciation of the levels of activities and expenditures that could be needed to address severe subsidence and disposal trench instability problems.

As was the case at several of the other disposal sites, when the Maxey Flats site was opened the regulatory attention was primarily focused on short-term protection of the human environment. There was no uniform criteria for the acceptability of a disposal facility after closure and for long-term care, and the long term condition of the disposal facility and the activities that may be required to keep it in a safe condition were not fully considered. There was a recognition that some manner of long-term maintenance (such as repairing small holes in trench covers, cutting the grass, maintaining the fences, etc.) would be required, and so funds were collected as a surcharge on received wastes and placed into a "perpetual care" fund. However, contingencies were not fully considered and there was no formal, routinely updated correlation between the amount of surcharge collected and the funds likely to be required for long-term care.

Much of this situation is believed to have grown out of an earlier perception -- that is, the prevailing attitude at the time the Maxey Flats and many other sites were licensed -- of LLW disposal being a rather mundane operation somewhat incidental to the use of radioactive materials and for purposes such as electrical power generation. Disposal facility licensing was carried out by AEC in a similar manner as "materials" licenses for use of radioisotopes. In recognition of the long-term nature of the disposed waste, the disposal facilities were all required to be owned by either the State or Federal government. In practice, the disposal facility sites are generally owned by the States who then lease the sites back to the operators (an exception is the Richland, Washington site which is located on Federally-owned land leased to the State and subleased to the operator). Frequently, however, the lease conditions at the disposal sites were

vague regarding the criteria for facility acceptability upon return to the State. In addition, since the potential environmental and economic impacts from LLW disposal were expected to be inherently small, early AEC disposal facility licenses were frequently very brief documents and stressed operational safety considerations with less emphasis on long-term considerations. Operating conditions contained in the early licenses were often vague and open to wide interpretation, with few specific requirements for regulatory bodies to inspect against and enforce.

The combination of the above factors has led to the difficulties at Maxey Flats in which a considerable amount of costly active maintenance activities in the form of liquid handling and treatment are required to preserve safety. Such activities are currently carried out under the conditions of a closed site, and of course there is no incoming waste to provide funds to help defray costs. Even when the disposal facility was operating, active maintenance activities such as leachate pumping and treatment probably represented a large source of expense without a tangible corresponding economic gain. Under these and similar conditions, the tendency is to try to maintain the site spending as little money as possible, and without addressing (more expensive) measures to eliminate the need for such active maintenance.

Over time, what was probably a relatively small, controllable liquid accumulation problem became a major source of expense. Although the evaporator at the site has been operating since 1973, it is only within the last few years that the processing rate of contaminated liquid has exceeded the accumulation rate. One of the factors contributing to this situation was the former practice of storing low-activity contaminated liquid in open on-site ponds. Since the disposal facility is located in a humid region and the ponds for several years were left open to rainwater, the volume of contaminated water grew. The ponds have been covered in the last few years.

In addition, early steps taken to address the cause of the water accumulation problem (which is trench cover subsidence caused by compression and degredation of the disposed waste) were not effective. After the trenches are pumped dry, the slumping and subsidence continued, leading to areas in the trench cover of increased infiltration, thus acting to fill the trenches again. This occurance was possibly augmented by the pumping process itself. The leachate standing within a trench occupies a certain volume within the trench, and when the leachate is removed a certain amount of void space is produced. This of course leads to subsidence and further trench filling. Measures taken in the past few years have been more effective and the rate of water accumulation is decreasing.

In any case, it is clear that unless adequate steps are taken to reduce subsidence through stabilization of the disposal trenches through mechanical or other means (heavy compaction, grouting, etc.), and trench covers that will prevent infiltration are installed, the process of leachate production and treatment will continue.

3.2 West Valley, New York

In 1963 Nuclear Fuel Services, Inc. (NFS), a subsidiary of W R. Grace and Co. (WRG) in which American Machine and Foundary (AMF) had a 22% interest, was established to construct and operate a commercial nuclear fuel reprocessing plant on land located near West Valley, New York (the Western New York Nuclear Service Center). The stock representing the 22% AMF interest in NFS was acquired by WRG in the early 1960's, making the operation a wholly owned subsidiary of WRG. In 1969, the NFS stock was acquired from WRG by the Getty Oil Co. (majority owner), and the Skelly Oil Co., a Getty subsidiary. The 1350 ha (3345 acres) of land upon which the NFS operation is sited is owned by the New York State Energy Research and Development Authority (NYSERDA), a public benefit corporation which is responsible for fostering development and use of various erergy sources in the State.

NYSERDA also administers an agreement with NFS for site operation and has financial responsibility relating to long-term care. Construction of the NFS facility was completed in 1966, and the facility was operated between 1966 and 1972 (Figure 3-3).[20]

NFS also operated two distinct radioactive waste burial areas at the facility. One of these areas is a site licensed by the Nuclear Regulatory Commission (NRC) for storage of cladding hulls, non-fuel bearing fuel components, and other miscellaneous high activity waste from the fuel reprocessing plant.[21,22] The other area was used to dispose of commercial LLW generated by hospitals, laboratories, nuclear power plants, industrial facilities, and the NFS reprocessing plant. This commercial disposal site is licensed by the State of New York, and occupies about 9 ha (22 acres) of land. The disposal site was operated by an NFS subcontractor as a public service obligation as condition of NFS's agreements with NYSERDA for operation of the reprocessing plant.

The commercial LLW disposal site accepted waste for shallow land burial between November 1963 and March 1975. In 1972, activities at the reprocessing plant ceased. In 1975, the disposal site operations were voluntarily suspended by NFS after a small quantity of leachate was detected seeping through the cover of one of the disposal trenches.

Since 1975, the reprocessing facility and burial areas have been maintained in a custodial status by NFS, although NFS in 1976 announced their intention of withdrawing from the nuclear fuel reprocessing business.[14] NFS also announced their intention under the lease agreement to return control of waste storage facilities (including about 600,000 gallons of stored liquid high level waste) to NYSERDA. A number of terms and conditions had to be met prior to transfer of the facilities, however, and the NFS announcement generated considerable legal, economic, political, and environmental debate. One of the concerns was that the funds held by NYSERDA for long-term

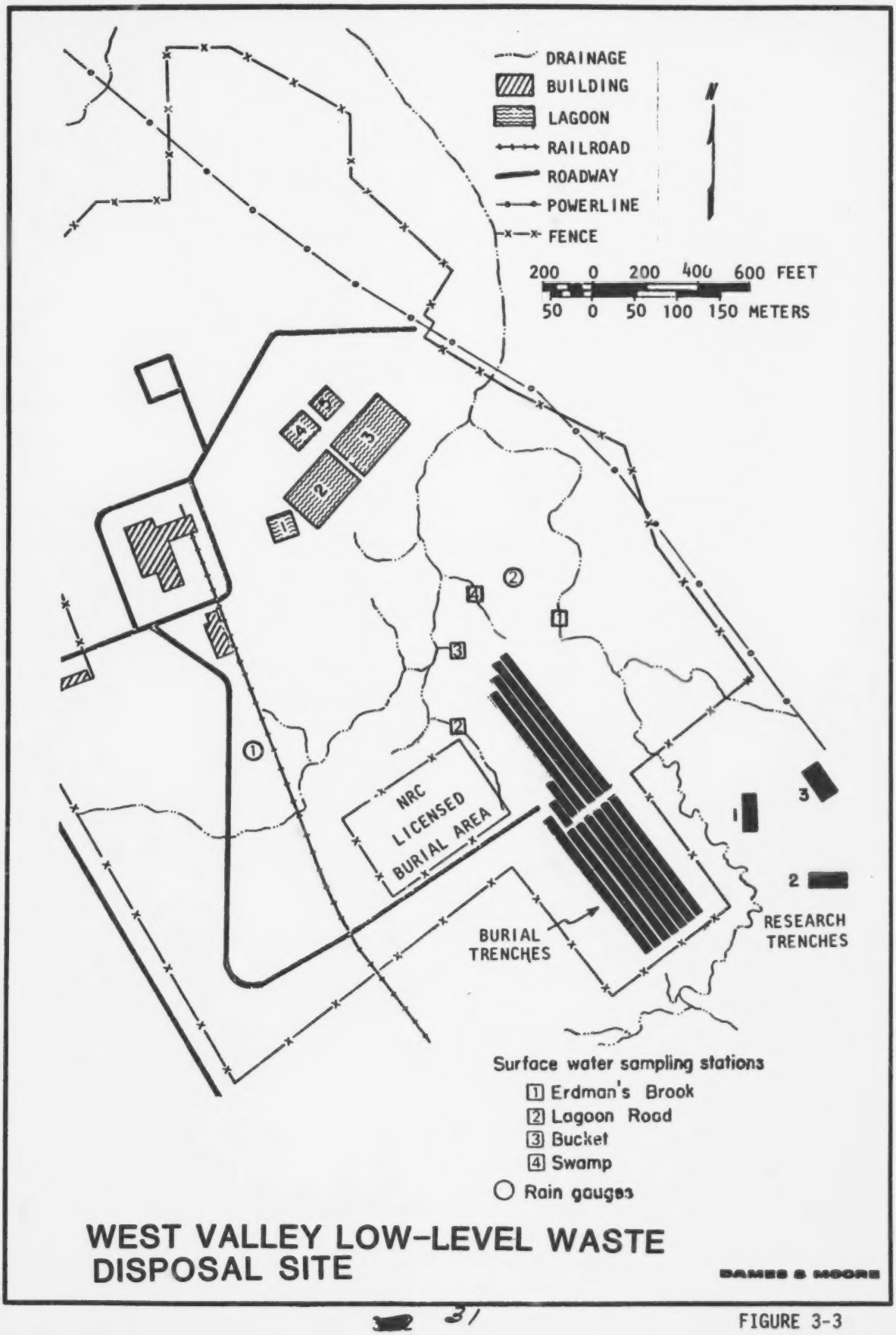

DRAINAGE
BUILDING
LAGOON
RAILROAD
ROADWAY
POWERLINE
FENCE
N
200 0 200 400 600 FEET
50 0 50 100 150 METERS
NRC LICENSED BURIAL AREA
BURIAL TRENCHES
RESEARCH TRENCHES
Surface water sampling stations
1 Erdman's Brook
2 Lagoon Road
3 Bucket
4 Swamp
Rain gauges
WEST VALLEY LOW-LEVEL WASTE DISPOSAL SITE
DAMES & MOORE

FIGURE 3-3

care of the facility were insufficient. More recently, NFS sought in December 1980 to turn the commercial disposal site over to NYSERDA. NYSERDA sought and obtained an injunction preventing this transfer and the matter is now in litigation. NFS continues to perform custodial care at the site.

The future disposition of the commercial LLW disposal site is related to a degree to the eventual disposition of the entire NFS site, including the fuel reprocessing plant and the stored liquid high level waste. Fairly recently, DOE published a report which addresses alternatives for eventual disposition of the site, including full or partial decommissioning or continued use as some manner of nuclear production or research facility.(23)

After completion of this study of alternatives, which was mandated by Congress, Federal legislation was passed in 1980 (the West Valley Demonstration Project Act) that charges DOE with the responsibility to develop, construct, and operate a high-level waste solidification demonstration project at the West Valley facility. This project will solidify the 600,000 gallons of liquid high-level waste presently stored in underground tanks to a final form acceptable for disposal into a Federal repository, and decontaminate and decommission the facilities used in the federal project. The material buried under the NRC license during plant reprocessing operations are part of the federal project.

A draft environmental impact statement has been recently published by DOE on this project.(24) Decontamination of existing facilities to prepare for the project, activities during the waste solidification project, and final decontamination of facilities at the end of the project will generate substantial volumes of low-level waste. Some of this waste is expected to be contaminated with transuranic (TRU) radionuclides. It has not yet been determined where these wastes will be disposed, but it appears that some of it may be consigned to DOE storage and disposal areas (TRU waste) and some may be disposed on-site.

3.2.1 Site Environmental Characteristics

The disposal area at the West Valley site was selected because of the absence of aquifers near the site surface, the low permeability and high absorptive capacity of the silty till soil, and the good surface drainage present at this location. The disposal site is located on a plateau with a surface elevation of 421 to 424 m (1380 to 1390 ft) above mean sea level (MSL), and is surrounded by drainage gullies on three sides with surface elevations of about 404 to 411 m above MSL (1325 to 1350 ft). The near surface soils (upper 3 to 3.5 m) generally consist of weathered till (a brown silty clay containing some gravel and rock). Below the surface soil lies 45 to 90 m (148 to 295 ft) of unweathered till which consists of a gray plastic silty clay containing occasional pebbles and rock fragments. The bedrock beneath the till material consists of shale and siltstone.[25-29]

The climate is cool, moist, mid-continental. The mean annual precipitation at the site is 1040 mm (41 in), most of which falls in the form of snow (3800 mm). The average annual temperature range of -18°C (0°F) to 32°C (90°F), with a mean of 7°C (45°F), is indicative of the wide variation in seasonal temperatures. The predominant wind direction is from the southwest at average speeds of 20 km/hr (12.3 mph), with highest wind speeds during the winter.[20-24]

Although the silty till is locally partially saturated, the till itself is not an aquifer. The horizontal permeability of the till ranges from 4.3×10^{-5} to 2.5×10^{-4} m/day; vertical permeabilities are of the same magnitude. At a well drilled on the eastern side of the disposal site, the aquifer was found to lie at a depth of 31 to 38 m (100 to 122 ft). A second aquifer has been observed at a depth of greater than 60 m (197 ft). Since the trenches were normally dug to a depth of 6 m (19.7 ft), the bottoms of the disposal trenches typically lie from about 25 to 32 m (82 to 104 ft) above the water table.[29-31]

The State-licensed disposal site is drained on the east side by Frank's Creek, and on the north and west by a small tributary of Frank's Creek. These small creeks discharge into Buttermilk Creek, which has an average discharge rate of 1.3 m^3/sec (46 ft^3/sec). Buttermilk Creek drains into Cattaraugus Creek, which has an average discharge rate of about 10 m^3/sec.[20,23,26]

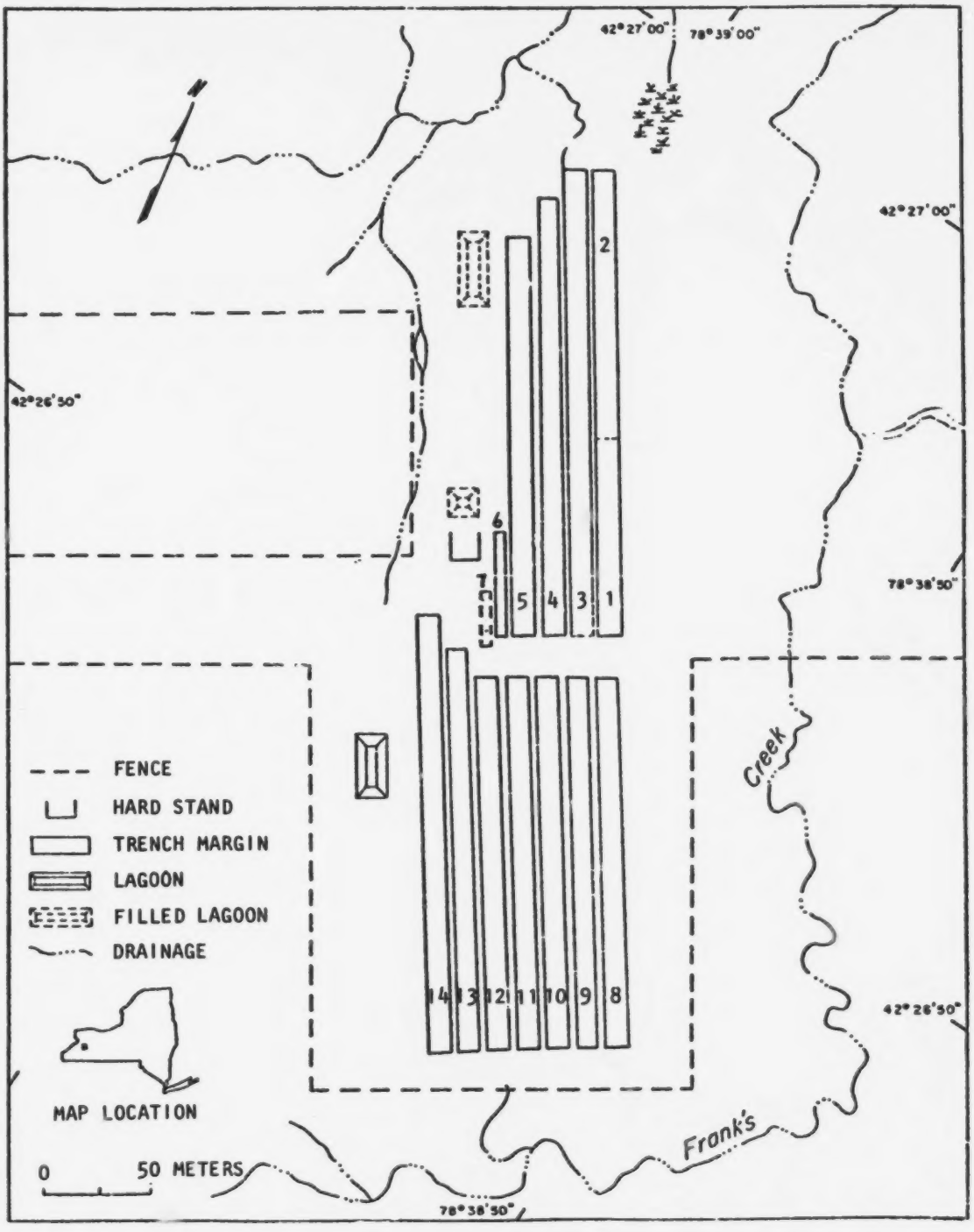
3.2.2 Disposal Experience

Background

Between November 1963 and March 1975, approximately 66,837 m^3 (2,360,000 ft^3) of radioactive waste containing 704,500 Ci of byproduct material, 465,394 kg (1,026,000 lbs) of source material, and 56 kg (123 lbs) of special nuclear material (including 4 kg of plutonium) had been disposed at West Valley. These wastes came from offsite medical, educational, research, industrial, pharmaceutical, federal installations, nuclear power plants and (about 20 %) from the onsite nuclear fuel reprocessing facility.[14,21,23,32]

The majority of waste buried at West Valley consisted of paper trash, animal carcasses, evaporator bottoms, filters, filter sludges, protective apparel, residues, plastic, glass and packing material. These materials were packaged in drums, liners, crates, bags and boxes. Through 1972, the predominant radionuclides reported as disposed at West Valley were tritium and ^{14}C (over 158,000 Ci), ^{60}Co (about 76,000 Ci), mixed fission products (about 20,843 Ci; presumably dominated by ^{137}Cs and ^{90}Sr mixtures), miscellaneous wastes or waste not specifically identified (totaling over 85,000 Ci), and ^{238}Pu (34,982 Ci).[21,23,32]

As shown in Figure 3-4, the disposal site consists of 14 shallow land burial trenches. Seven trenches were constructed in the northern area of the site between 1969 and 1975. Three of these trenches (trenches 3, 4, and 5) are relatively long and narrow and measure about 180 to



WEST VALLEY LOW-LEVEL WASTE DISPOSAL SITE

New York State Geological Survey 7/79

DAMES & MOORE

FIGURE 3-4

240 m (792 ft) in length, about 10 m (33 ft) in width, and about 6 m (20 ft) in depth. It was once thought that trenches 1 and 2 were one long continuous trench; however, trench water (leachate) differences suggest that one trench is hydrologically disconnected from the other. Trench 6 is not a true trench but rather a series of individual bore holes for waste with high external exposure rates. Trench 7 is actually a narrow and shallow concrete vault. The spacing between the trenches in the northern area was typically between 1.5 and 2.0 m (4 and 7 ft).

The disposal operation was a cut and fill type operation which involved only segments of the trench (45 to 60 segments total) being excavated at a time. The length of these excavated segments was largely dictated by the volume of waste which had accumulated for disposal. After the waste was emplaced, less than 15 m (in length) of the trench was exposed to the weather. This minimized the quantity of rainfall accumulated in the active trench. Two lagoons adjacent to the northern area were used to hold rainwater pumped from the open disposal trenches. The lagoon area has since been reclaimed.

The potential for water accumulation in covered disposal trenches was apparently anticipated. Drains were installed in the trench floors leading to sumps into which standpipes had been emplaced. From 1963 until being required by the State to stop in 1968, NFS routinely periodically pumped leachate out of the trenches and discharged the leachate, after considerable dilution, into an adjacent stream.[33]

The seven trenches in the southern area of the disposal site are approximately 180 m (594 ft) in length, 10 m (33 ft) in width, and 6 m (20 ft) in depth. Several improvements in trench construction were employed for these trenches including the following: (1) stripping topsoil and coarse sediment from the area, (2) increasing separation between the trenches to a minimum of 3 m (10 ft) to minimize slope failure and potential lateral migration between trenches, (3) sloping the floor of each trench away from the working end (end where waste

was emplaced) at approximately 0.6 m vertical per 180 m horizontal; (4) capping and mounding trenches separately (as opposed to the general mounding performed in the northern area) which minimizes time uncapped and provides for better drainage, and (5) doubling the thickness of the trench caps (from 1.2 m up to 2.4 m).

A lagoon was constructed adjacent to the southern area trenches to hold rainwater which was pumped from open trenches. This lagoon and the two lagoons in the northern area were connected by pipeline to the low-level waste treatment facility located in the nearby fuel reprocessing plant. At the plant, the rainwater was decontaminated and then discharged.[27,28]

The license for the waste disposal area[34] stipulated that each trench be inspected before use. The criteria for acceptability include continuity of the silty clay and a lack of significant perched saturated horizons. In the event a significant perched saturated horizon was encountered, specific authorization from the state was required. An inconvenience was that the inspections had to be performed in segments because the trenches were excavated and used in segments to minimize rainwater inclusion. The state license also required that the disposal operations be conducted in a fashion which minimized potential dispersion of radioactive material by weather (e.g., wind and water) or wildlife.

Most of the waste delivered to the disposal facility and disposed was packaged in 55-gallon steel drums. Wastes having a radiation level at the container surface in excess of 200 mR/hr were required to be solidified in concrete. Many of the waste containers were placed (rolled or dropped) into the trenches by hand. Heavy containers and packages with high external radiation levels were placed into the trench with the aid of a large capacity crane. Many of the 55-galllon drums were stacked in place.

The original license for the site required that the wastes be disposed

so that at least 1.2 m (4 ft) separated the top of the waste from the surface grade. In 1965, the license was amended to allow filling of the trench up to surface grade. The disposal trenches are each marked with a concrete monument at each end. An engraved plate has been emplaced on each monument containing information on trench dimensions and contents.[34]

After trench completion, certain monitoring and maintenance operations are required by the license. These requirements include weekly measurement of liquid levels in open (working) trenches and monthly liquid level measurements in closed (completed) trenches. The State license requires that a completed trench be maintained by a proper vegetative cover (e.g., shallow rooted grass to prevent erosion) and by prompt filling of any subsidence holes or fissures that appear more than 0.6 m (2 feet deep). If surface ponding or trench cover depression occurs, the license requires that appropriate maintenance regrading, refilling, and revegetating be performed.[34]

Problems Encountered

The main performance problem which has occurred at the West Valley facility is accumulation of leachate within the disposal trenches. Erosion of a portion of the disposal site is another factor which should be considered over the long term.

In the early 1970's, the State of New York detected small increases in the levels of tritium concentrations in the streams adjacent to the LLW disposal area. As a result of this observation, a study to determine the source of this contamination was performed in 1973 and 1974. The study included a subsurface investigation (including vertical borings) around the periphery of the disposal site. Although this study revealed no evidence that suggested extensive migration out of the disposal trenches, excessive accumulation of water into trenches 3, 4, and 5 was indicated by the data.[35]

The monthly liquid level measurement in the trench monitoring sumps revealed a steady rise (1.5 to 3 m) during the first two years after each trench was completed. After rising several meters, these liquid levels remained fairly constant except in trenches 3, 4, and 5. The water level in these three trenches initially rose but then stabilized until 1971. In 1971, the water levels in trenches 3, 4, and 5 began rising again. The rising water levels were recorded by NFS and reported to the State of New York. NFS requrested permission to pump leachate and treat it for release. No specific action was taken. In March 1975, the water level reached the ground surface level and broke through the cover of trench 4 in the form of a seep. The flow rate from this seep was estimated to be about 4 liters (1 gal) per day.[21] The site operator stopped disposal operations at the site after discovery of this seep. The disposal site has remained closed since that time.

After the observance of the seepage from trench 4, the State of New York granted permission to NFS to pump accumulated water out of trenches 3, 4, and 5. Between March and April of 1975, about one million liters (264,000 gal) of leachate was pumped from these trenches. The leachate was transferred after pretreatment (chlorination and flocculation) to the low-level liquid waste treatment facility located in the on-site reprocessing plant for decontamination. Pumping of water from these trenches continued sporadically for a year and a half. Between March of 1975 and October of 1976, over 6.4 million liters (1.69 million gal) of leachate was pumped from these three trenches. This pumping lowered the water level in the disposal trenches by approximately 5 meters.[27,35] Additional pumping and treatment activities occurred in 1978 and 1980.[33]

The leachate is contaminated with radionuclides from the buried waste. Observed gross alpha activity ranges from less than 200 to 2.9 million pCi/l, while observed gross beta activity ranges from

91,000 to 31 million pCi/l (1977 data). The concentrations of tritium in leachate range from 220,000 to 5.6 million pCi/l. The principal gamma emitting radionuclides observed in trench leachate are ^{137}Cs, ^{134}Cs, ^{60}Co, and ^{241}Am. Concentrations of ^{137}Cs have been observed to range from less than 160 to 900,000 pCi/l. The observed concentrations of ^{134}Cs range from less than 110 to 330,000 pCi/l. The observed concentrations of ^{60}Co and ^{241}Am have ranged from less than 110 to 10,000 pCi/l and less than 170 to 1,110 pCi/l, respectively.[9] The northern end of the trenches in the northern trench area has also experienced some erosion in the form of gullies. When erosional gullies appear in the trench cover, maintenance work is performed to alleviate the problem.[28,35]

From March 1975 to the present the site has been maintained in a shutdown condition with some pumpouts of leachate from the trenches. Water has also accumulated in the southern area trenches, although the accumulation rate has not been as dramatic as that observed in the northern area trenches. The trench covers in the southern area are thicker (2.4 m vs 1.2 m) than those in the northern area.[21,22,36] In August 1978, a preliminary trench cover remedial program was initiated for the northern area trenches.[37] This remedial program primarily consisted of the addition of 1.2 m (4 ft) of compacted silty till to the existing covers of northern trenches. The surface drainage pattern of the area was also modified. The trenches in the southern area were reworked in 1980. In this case, 1.2 m (4 ft) of earth covering the trenches was stripped off and then replaced and compacted.[33]

The disposal trenches appear for now to be reasonably stable. The standing water level in the trenches is monitored carefully, and if the water level in a trench is observed to rise more than a few inches, the trench cover is recompacted using a vibratory roller.[33]

3.2.3 Discussion

In retrospect, it appears that there are no natural environmental characteristics at the West Valley disposal site which would preclude safe disposal of LLW. There has been no significant migration of radionuclides through the soil and into the groundwater, and there have been no significant problems with surface contamination. The major physical problem at the site has been the accumulation of leachate within the disposal trenches, although the magnitude of the accumulation problem appears to be much less than at Maxey Flats. Unlike at Maxey Flats, more direct action was taken to reduce the accumulation rate -- i.e., the remedial work performed on the northern trenches. This remedial work has reduced infiltration into the trenches and has therefore reduced the extent of water accumulation. Another concern is the erosion experienced at the northern end of trenches in the northern area. In this case, some of the disposal trenches were excavated close to a steep incline as illustrated in Figure 3-5. This concern, however, can probably be remedied by straightforward engineering techniques.

Institutional considerations are believed to have greatly contributed to the water accumulation problems. The site was opened without sufficient attention given to closure and potential long-term maintenance requirements. Emphasis was given to the health physics aspects of operating the site. Furthermore, operation of the reprocessing plant received the major portion of the regulatory attention while the question of the eventual disposition of peripheral systems such as the burial areas was left to be handled in the future.

Like most other disposal facilities, when the site was first opened, the natural site characteristics alone were expected to completely contain the disposed radionuclides. Consequently, since the site environmental characteristics were such that potential groundwater migration was expected to be minimal, and since much of the waste so disposed was of very low activit , not much consideration was given to

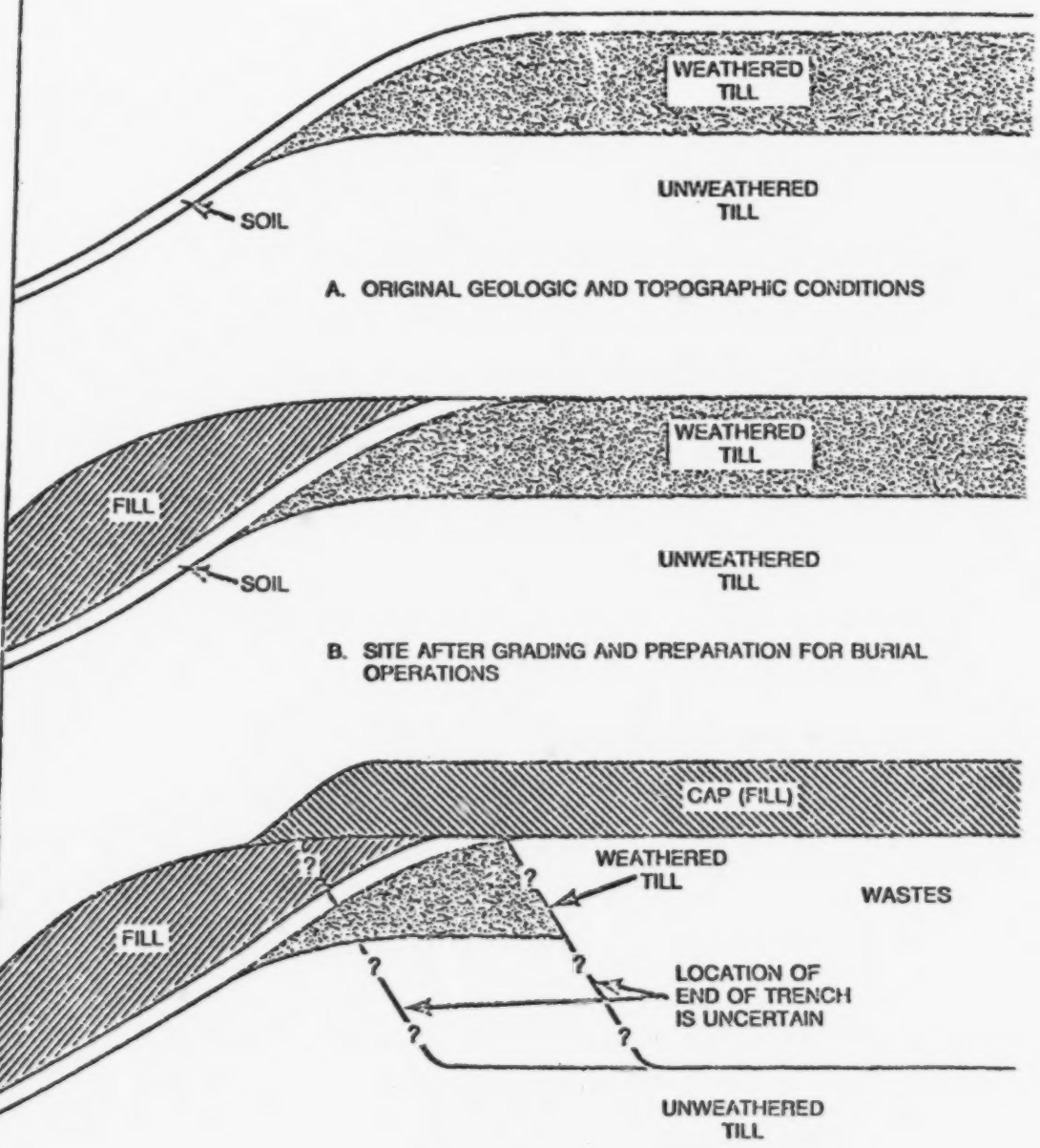

WEATHERED TILL
UNWEATHERED TILL
SOIL
A. ORIGINAL GEOLOGIC AND TOPOGRAPHIC CONDITIONS
WEATHERED TILL
FILL
SOIL
UNWEATHERED TILL
B. SITE AFTER GRADING AND PREPARATION FOR BURIAL OPERATIONS
CAP (FILL)
WEATHERED TILL
WASTES
FILL
LOCATION OF END OF TRENCH IS UNCERTAIN
UNWEATHERED TILL
C. SITE AFTER BURIAL OPERATIONS COMPLETED
DAMES & MOORE

FIGURE 3-5

waste degredation and trench cover subsidence. The reprocessing plant was expected to be operating for several tens of years, and while it was thus operating, any required maintenance could be easily performed.

Reprocessing operations were terminated at a much earlier date than expected, however, as were waste disposal operations. There were no incoming funds to help offset costs for required maintenance activities. Meanwhile, the combination of unstable trench covers (caused by degradation of compressible wastes, formation of voids, and subsidence), low permeability soils, and a humid environment, had brought about a condition in which the required maintenance activities involved handling large quantities of liquids. Remidial actions such as regrading trench caps have also been required. Such "active" maintenance activities are obviously more expensive than would have been the case if the site had been designed and operated so that only "passive" maintenance (e.g., filling small holes, cutting the grass, maintaining the fence) had been required.

3.3 Sheffield, Illinois

The Sheffield disposal site, which is shown in Figure 3-6, is located in northwestern Illinois about 5 km (3 miles) west to southwest of the town of Sheffield. The State-owned area which comprises the disposal site is 8.3 ha (20.5 acres). The surrounding 68 ha (168 acres) are owned by the site operator and are predominantly used for industrial waste disposal (16 ha or 39.5 acres) and farm leases (48.8 ha or 120 acres). Land nearby the site is used for farming (crops and pasture), and has also been used for strip mining of coal.[38]

Use of the Sheffield site for disposal of low-level waste was initiated in August 1967. The site was originally operated by California Nuclear, Inc. but the site license was transferred to Nuclear Engineering Company (NECO) in 1968. This site was operated by NECO -- now

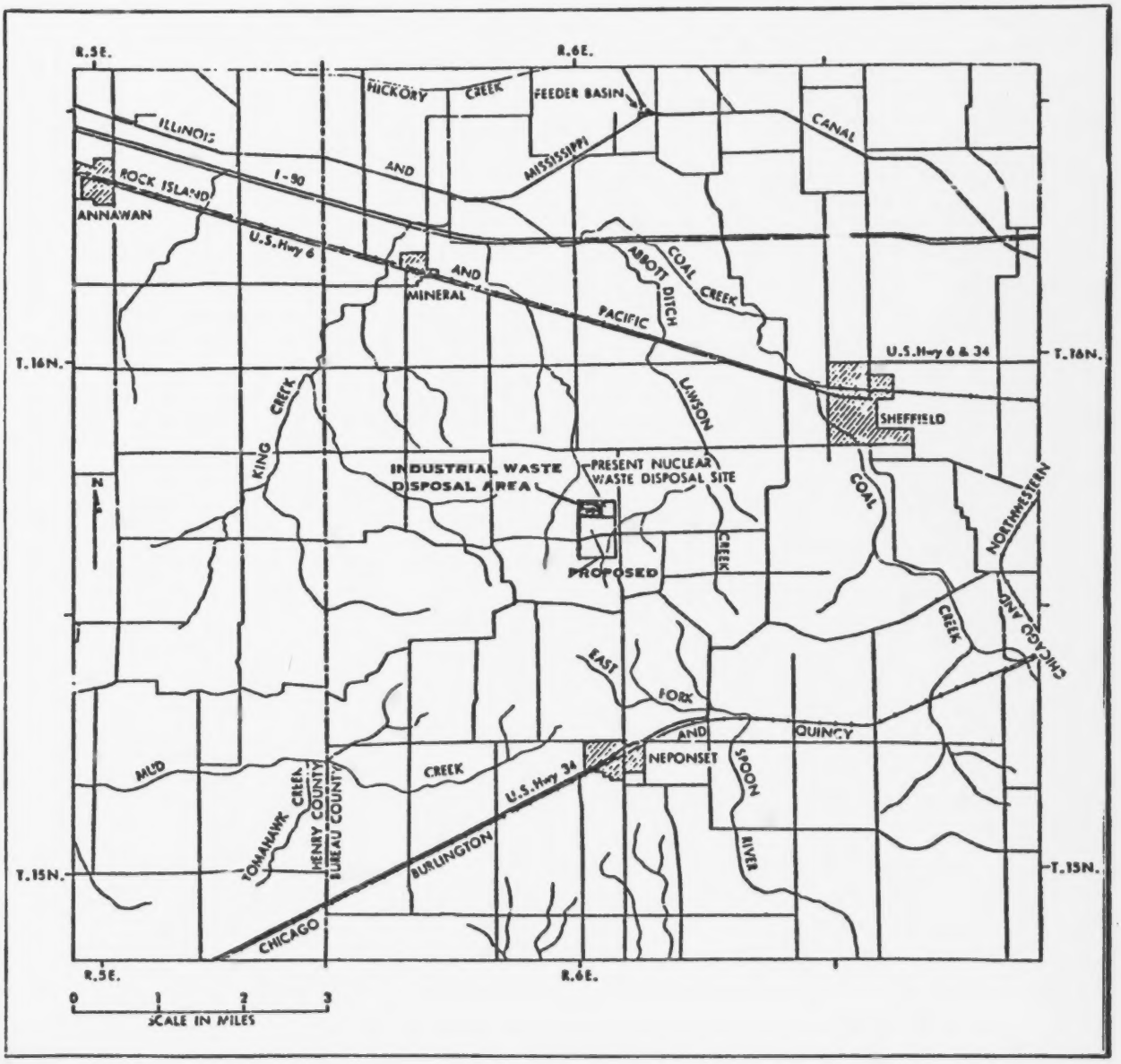


FIGURE 3-6
VICINITY OF SHEFFIELD SITE

U.S. Ecology, Inc. (USE) -- from 1968 to the present. Since April 1978, the facility has been closed and no waste has been accepted for disposal.(39)

Like four of the other five disposal sites (the Richland, Washington site is the exception), the Sheffield site is on land owned by the State. However, it is the only site not located in an Agreement State and possession and disposal of source, byproduct, and special nuclear material is therefore licensed by NRC. The State has also issued a license for possession and disposal of radioactive material, such as naturally-occuring and accelerator produced materials, not regulated under the Atomic Energy Act of 1954.

In 1976, USE filed an application to NRC and the State for site expansion from 20 acres to 188 acres, anticipating shortly running out of licensed disposal area. Hearings on the NRC application were requested and an Atomic Safety and Licensing Board (ASLB) was established. The last available licensed trench was filled on April 8, 1978.(39) USE then requested suspension of the licensing proceeding in December 1978, and termination of the proceeding in March 1979. The ASLB, however, allowed USE to withdraw the application for expansion but not for renewal. USE then (March 8, 1979) attempted to unilaterally terminate the NRC license as well as the State license and lease, and abandon the site. In so doing, USE asserted that they had complied with NRC and State regulations, NRC and State license conditions, and the term of the lease, and were therefore legally entitled to take their action. Both NRC and the State issued orders requiring USE to return to the site. Following USE's reluctance to comply with the orders (USE took the position that since they were no longer a licensee of the State and NRC, they were under no obligation to obey the orders.), the State filed suit in circuit court seeking judicial relief. The State won a preliminary injunction ordering USE back to the site while a final settlement was developed. This case is still pending. USE has since signed an agreement with NRC to provide site

security and monitoring and maintain the site until the legal issues are resolved. USE has requested a hearing on the NRC order and the matter has been referred to the same ASLB. A decision from the ASLB regarding the transfer of the site to the State and the condition of the site when it is transferred is still pending.[39]

3.3.1 Site Environmental Characteristics

The disposal site is located within the Glaciated Till Plain section of the Central Lowlands physiographic province. Bedrock at the site consists of sedimentary rocks of Pennsylvanian age. This bedrock material is overlain by about 18 m (60 ft) of glacial silt, clay, and sands. The upper 137 m (450 ft) of the bedrock underlying these glacial sediments is generally composed of low permeability shales and limestones. The permeability of the majority of the subsurface soils (sediments) is quite low. Locally, clayey sands and clayey gravels occur in the upper 20 m (96 ft) of the glacial deposits. These coarser grained sediments have higher primary permeabilities than the clayey silts and silty clays which predominate in the subsurface at the site.[38,40]

The climate at the Sheffield site is humid continental with cold winters and warm to hot summers. The average annual precipitation rate is 891 mm (35 in) with the majority of the rainfall occurring between April and September (the agricultural growing season). Annual snowfall averages about 750 mm (29 in).[38,40] The prevailing winds at the Sheffield disposal site are from the south and southwest between May and October (which bring in tropical air masses) and from the northwest between November and April (which bring in arctic air masses). The average annual wind speed at Peoria (72 km away) is about 17 km/hr (10.6 mph) from the south. The highest wind speeds are usually encountered during the winter and early spring. During the last 10 years, the maximum and minimum recorded temperatures have been approximately 39°C and -32°C (102 and -25°F), respectively.[38,40]

The depth to ground water at the site ranges from 6 to greater than 15 m (14 to greater than 34 ft) below the original ground surface. In general, the water table is a subdued replica of the surface topography. It is estimated that of the 891 mm (35 in) of precipitation occurring annually, about 62 mm (2.5 in) of water makes its way to the water table.[38,40]

3.3.2 Disposal Experience

Background

Between 1967 and April 1978, approximately 90,524 m^3 (3,196,000 ft^3) of low-level solid waste containing over 60,200 Ci of byproduct material was disposed at the site (Table 3-3). The quantities of source material, special nuclear material, and plutonium disposed at the site were 271,793 kg, 55.9 kg, and 13.41 kg, respectively. The State license at the Sheffield site generally limited the concentration of disposed radioactive material to 1 curie per cubic foot (35 Ci/m^3), although some exceptions were made on a case by case basis.[39] Liquids were occasionally received on site and were solidified in urea-formaldehyde or cement. Disposal of plutonium waste at the site was discontinued in 1975.[39]

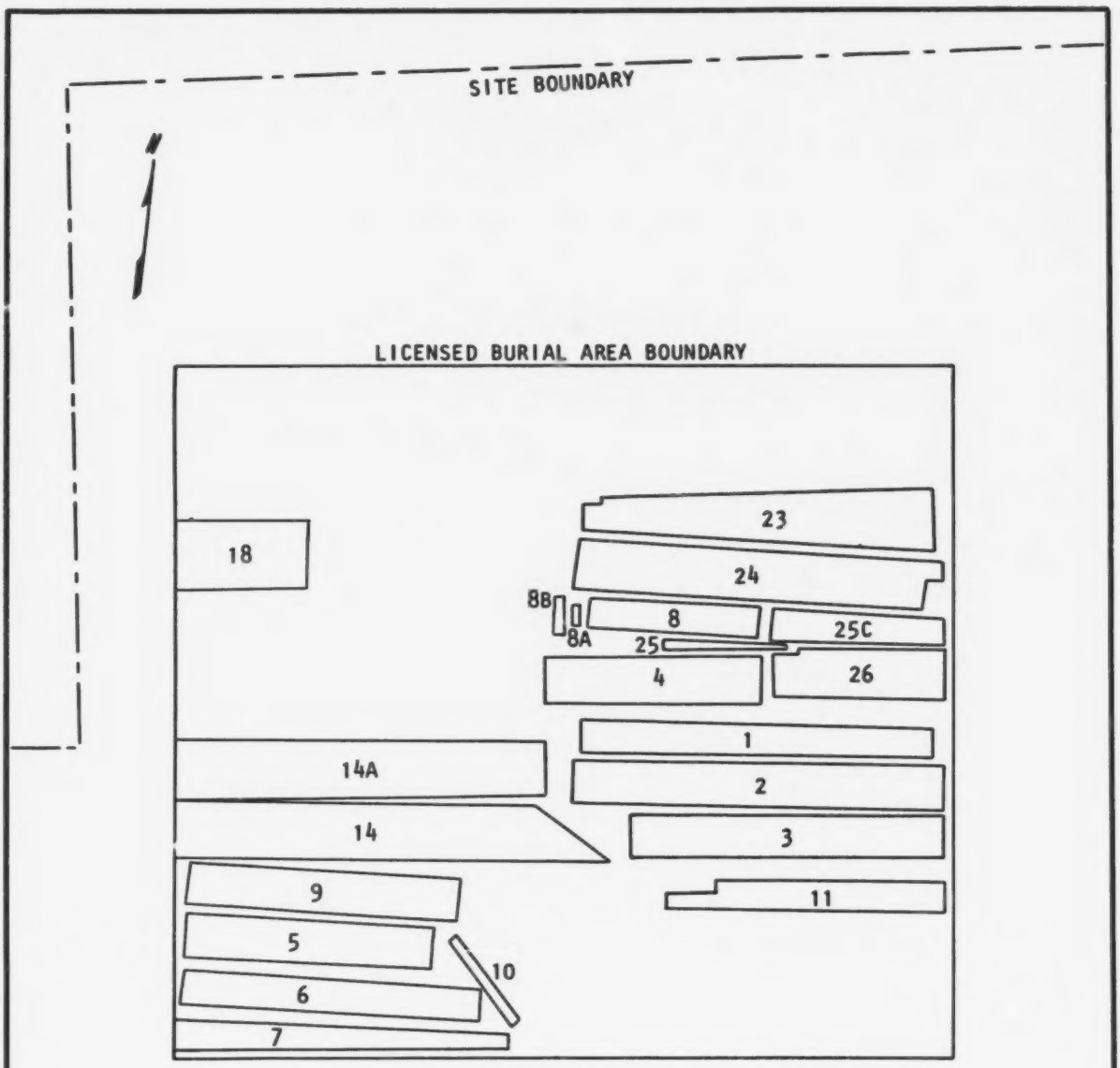
The disposal trenches at Sheffield have dimensions generally ranging from 61 to 152 m (200 to 488 ft) in length, 12.2 to 24.4 m (40 to 80 ft) in width, and 6.1 to 12.2 m (20 to 40 ft) in depth (Figure 3-7). Except for Trenches 14 and 14A, the trenches have been constructed in a cut and cover operation. Trenches 14 and 14A have been constructed partially above grade by means of compacted fill. With the exception of several slit trenches, the trenches have been excavated roughly parallel to one another with about 3 m (10 ft) spacing separating the trench side walls. All trench tops are above the probable maximum flood elevation and the trench bottoms (with the exception of Trench 18) are above the maximum ground water elevation. The bottoms of the

TABLE 3-3

Summary of Contents of Sheffield Trenches*

Trench Number	Date Open	Date Closed	By-Product (Curies)	S.N.M. (Grams)	Source Material (lbs)	Volume Buried (Cu. Ft.)
1	08/ /67	08/26/78	4,977.53	2,929.50	14,995.87	144,817.00
2	08/ /68	03/31/71	10,451.15	12,695.86	37,736.06	231,239.67
3	03/ /71	05/15/72	7,758.19	8,339.91	4,310.80	191,201.44
4	05/ /72	04/06/73	4,443.43	4,863.65	3,980.75	197,898.39
5	04/ /73	08/31/73	1,167.66	3,187.33	5,163.95	136,419.24
6	08/ /73	03/22/74	1,372.49	7,040.17	475.32	211,677.27
7	03/22/74	06/24/74	635.76	1,640.73	1,356.00	133,709.37
8	07/03/74	08/09/74	354.96	0	0	49,364.70
8A	05/16/75	05/28/75	237.99	0	0	3,178.30
8B	05/28/75	06/06/75	250.67	0	0	2,653.25
9	07/18/74	02/18/75	1,385.02	912.94	29,613.79	185,237.52
10	08/21/74	01/02/75	381.93	0	0	13,945.10
11	12/18/74	06/04/75	1,466.94	683.33	32,947.73	92,409.94
14	01/06/77	09/12/77	7,197.06	2,346.39	133,139.7	394,399.8
14A	08/12/77	04/08/78	6,321.50	5,097.63	272,100.89	351,877.34
18	03/29/76	12/06/76	131.30	99.0	198.00	120,655.69
23	08/10/76	01/13/77	4,565.03	211.27	6,622.66	184,450.75
24	06/27/25	05/24/76	5,109.38	4,285.61	24,123.72	227,695.83
25	02/20/75	05/15/75	195.89	0	0	14,525.30
25C	04/13/76	08/06/76	863.86	177.58	622.25	65,579.83
26	05/30/75	08/27/75	991.20	1,087.80	29,611.79	166,137.91

* Source : Reference 43



SHEFFIELD LOW LEVEL WASTE SITE
DISPOSAL AREA

0 100 200
SCALE IN FEET

DAMES & MOORE

FIGURE 3-7

trenches were sloped toward one end and are equipped with French drains that lead to sumps and riser pipes for sampling. Each trench has been capped and mounded for surface drainage.[39]

Problems Encountered

Three principal physical problems have been encountered at the site: erosion, subsidence, and elevated radionuclide concentrations in some groundwater samples obtained from some on-site wells and disposal trench sumps. These are discussed below.

It has been observed in the Interagency Task Force Report[39] that the site geology and hydrology are much more complex than originally thought when the site was licensed, and that "release agents such as water erosion, subsidence, mass wasting and frost action are of concern at Sheffield." It was also pointed out that geotechnical studies needed to be made of the erosion rates expected at the site. A subsequent study on the surface conditions at the site indicated and documented that surface erosion from runoff has resulted in the formation of rills and gullies.[41] Many of these features were found to be less than one foot deep. It was also pointed out that the surface drainage at the site could be improved through the development of an integrated drainage plan. This plan would reduce both infiltration and erosion.[41]

Trench subsidence has also been documented. The Interagency Task Force Report quotes a March 19, 1979 trip report by NRC staff that indicated the presence of several large sinkholes one of which (east end of Trench 24) was approximately ten feet deep and eight feet by twelve feet in area.[39] The sinkholes were subsequently filled in by the site operator, more recent observed subsidence depressions have not been as extensive. A subsequent report on the evaluation of trench subsidence and stabilization at Sheffield site concludes that the existing data on subsidence, waste characteristics and placement,

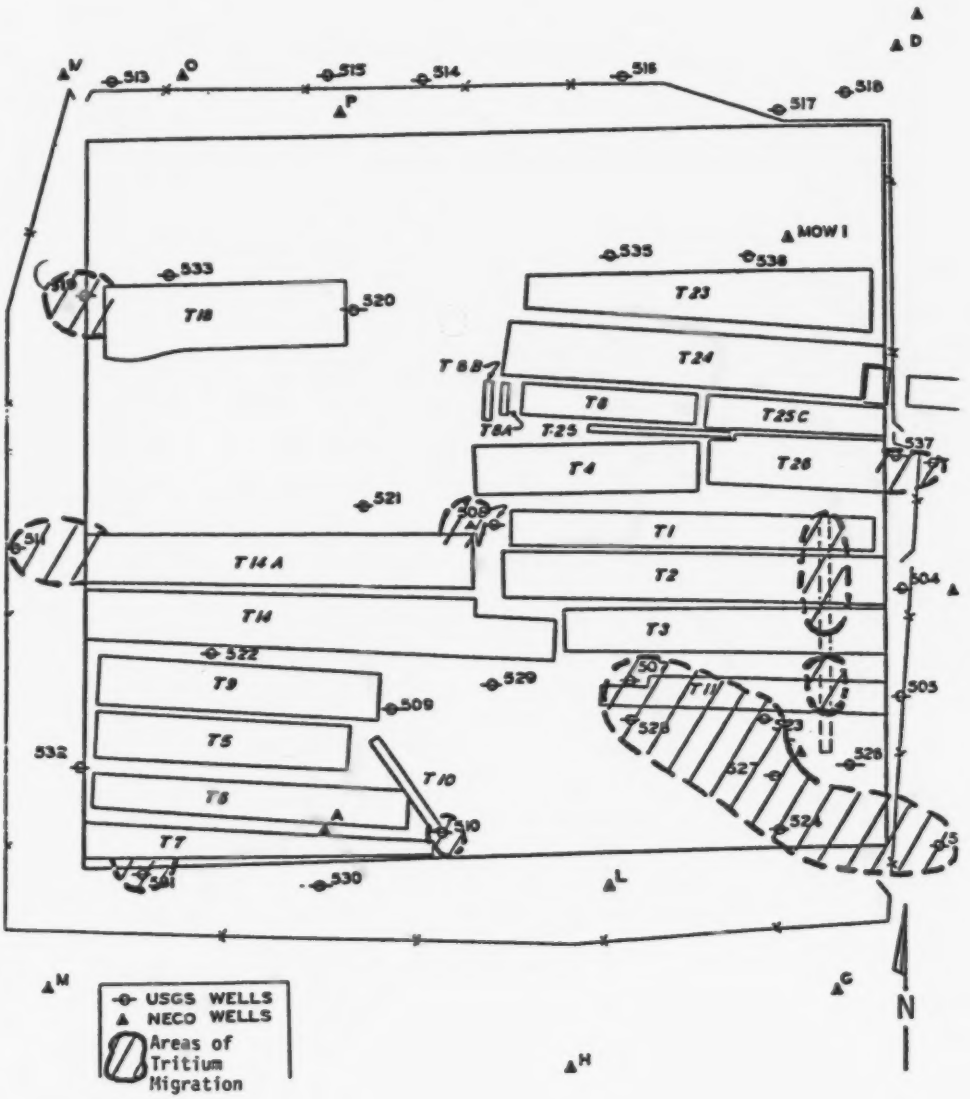
and backfill soil placement and compaction in each trench was not sufficient to accurately predict future subsidence trends in specific trenches.[42] The report further concludes that subsidence as it has occurred to date at the Sheffield site, is dependent on the amount of infiltration of surface water through the existing caps, and that all trenches have a potential for some future subsidence due to piping of soil, natural soil consolidation, and deterioration and settlement of disposed waste materials and containers.[42]

Elevated radionuclide concentrations in water obtained from on-site wells has been documented in the Interagency Task Force Report.[39] The major radionuclide that has been confirmed as migrating within the groundwater has been ^{3}H. The tritium migration appears to have occurred in several areas around the site as shown in Figure 3-8.[39] To date, however, the tritium has not exceeded the concentrations for tritium listed in Table II, Appendix B, 10 CFR Part 20.

Elevated concentrations of some radionuclides, particularly tritium, have also been observed in samples obtained from Trench 18 sumps. Trench 18 was excavated at a topographic low point on the site and during excavation, a muddy seam was encountered. As approved by NRC the trench was then partially refilled with earth to raise the trench bottom above what was believed to be the level of the water table underneath the trench. Since the final trench bottom was less than a foot above the water table, the contents of the trench was restricted to very low-activity material -- principally dirt contaminated from a liquid spill at a nuclear power plant. The water table beneath Trench 18 later rose, inundated the bottom few feet of the disposed waste containers.[39,42]

3.3.3 Discussion

The performance of the Sheffield site has shown some of the same types of problems as the other facilities. There were also some



AREAS OF TRITIUM MIGRATION AT SHEFFIELD SITE

DAMES & MOORE

FIGURE 3-8

improvements in occupational health physics and in handling and control of radioactive materials. There have been no problems with significant contamination of grounds and equipment. In addition, some improvements in the mechanics of trench construction (spacing of trenches, installation of drains, sumps, and riser pipes, etc.) are seen. There has also been better record keeping regarding the locations of disposal trenches.

It appears that certain site characteristics have contributed to the problems encountered. This is not because the site characteristics in themselves prohibit safe waste disposal, but because they were not adequately characterized during initial site investigation nor taken into account during site design and operation. For example, the Sheffield site is located on rolling terrain with occasionally moderately steep slopes, making surface water management difficult. The near-surface geology at the site is somewhat complex, with site soils consisting of wind-blown, uniform silt deposits (loess) underlain by glacial tills. The loess is highly erosive to wind and running water, susceptable to internal piping by percolating water, and loses strength when saturated. The tills are typically clay, except for sand and gravel outwash deposits between and underlying the tills. Initial site borings were interpreted as having scattered, isolated sand and gravel lenses. However, later borings and a tunnel constructed underneath the site by USGS showed the sand and gravel deposits to be laterally continuous under a major part of the site.

In addition, past cases of inadequate revegetation, introduction of steep slopes, and improper drainage design, installation, and maintenance have caused erosion concerns and additional drainage problems. In one case, a trench was constructed in a topographic low point with inadequate separation between the waste and the water table. In other past cases, surface water drainage has led across the tops of closed disposal trenches. More recently, however, the site operator has taken steps to address and mitigate the above concerns.

Although little or no leachate pumping activities are required at the site, the trench subsidence and slumping problems observed are generally similar to those experienced at the Maxey Flats and West Valley sites. Much of the waste was probably easily degradable or was packaged with large void spaces within the waste containers. Void spaces probably also existed between disposed waste packages, and insufficient care may have been given to compacting backfill and disposal trench covers. The subsidence and trench slumping has led to increased infiltration of rain and surface water, leading to increased potential for groundwater migration as well as increased maintenance requirements. It is unlikely, however, that significant off-site releases will occur.

Compensating for the above negative factors is the relatively low concentration and inventory of radionuclides at the site. Wastes delivered to the site were generally restricted to those having concentrations less than one curie per cubic foot, and the site inventory of byproduct material (60,000 Ci of mostly short-lived radionuclides) is by far the lowest of the six commercial sites. In addition, the level of maintenance would appear to be significantly less than that at West Valley or Maxey Flats. This is mostly due to the nature of the site soils, which are more permeable than those at the other two sites, and consequently there is less potential for a water accumulation problem.

Still, it is apparent that significant expenses will be required over several years to ensure that potential releases are maintained to levels as low as reasonably achievable. These expenses were not planned for at the time that the facility was opened. As in the case of Maxey Flats and West Valley, the site was opened and operated without specific criteria for the condition the site would be in upon transfer to the State (the degree of site stability after closure, the level of maintenance required over the long-term, etc.) During operations, the site operator prepared a maximum site utilization

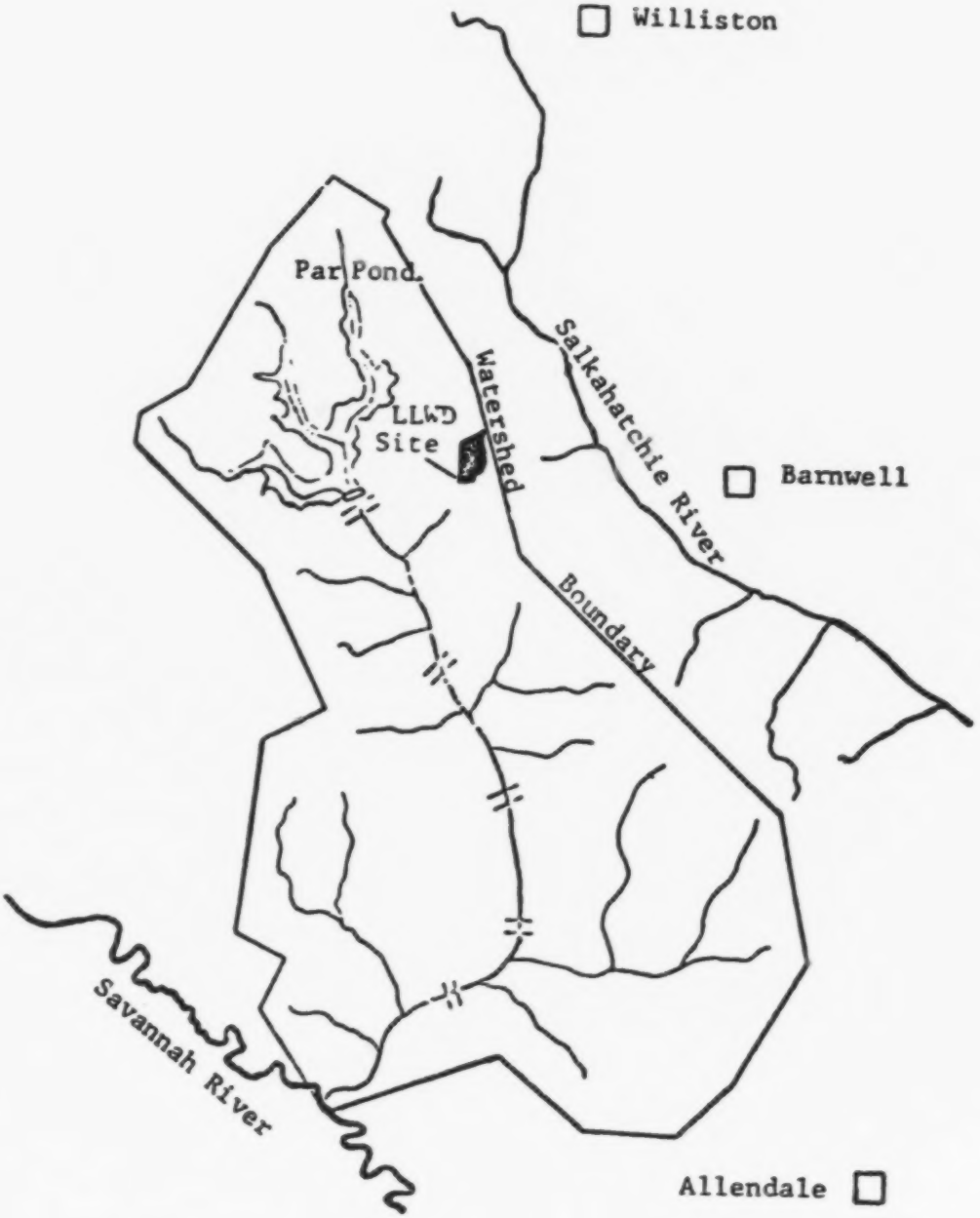
plan,[40] which included provisions for site surface water management and erosion control, but waste disposal was terminated prior to complete implementation of the plan. The problem is that such a plan was not made a condition of license operation at the time the facility was originally licensed. Although funds were collected for "perpetual care" as a surcharge on received waste, the amount of funds collected was inadequate. There was no provision to formally correlate and update the amount of funds that would have to be collected with the amount of site maintenance expected. In early years of site operation, the collected funds were placed into the State's general funds rather than into a dedicated interest-bearing account.

3.4 Barnwell, South Carolina

A commercial low-level radioactive waste disposal site has been operated by Chem-Nuclear Systems, Inc. (CNSI) since 1971 at a site located about 8 km (5 miles) west of the town of Barnwell, South Carolina (Figure 3-9). In addition to waste disposal operations, the site is headquarters for other CNSI activities, including mobile waste solidification and waste transportation services.[44-46]

As South Carolina is an Agreement State, most of the activities at the site are regulated by the South Carolina Department of Health and Environmental Control. The site operator holds a license from the State for possession and disposal of source and byproduct material, as well as a license from NRC for possession and disposal of special nuclear material.

By late 1979, the Barnwell site was the most heavily utilized site in commercial radioactive waste disposal history, and for a brief time was the only operating commercial low-level waste disposal site in the United States. (See Appendix A for volumes of waste disposed.) In October of 1979, when the monthly waste acceptance rate had risen to



VICINITY OF BARNWELL, SOUTH CAROLINA SITE

DAMES & MOORE

FIGURE 3-9

7062 m^3 (200,000 ft^3) implying an annual rate of 2.4 million ft^3), the Governor of South Carolina announced that the monthly acceptance would have to be reduced to 3431 m^3 (100,000 ft^3) by October 31, 1981. After October 1981, the Barnwell site will accept 42,372 m^3 (1.2 million ft^3) annually, regardless of the potential site capacity.(47)

3.4.1 Site Environmental Characteristics

The Barnwell disposal site is adjacent to the eastern boundary of the Allied General Nuclear Services' Barnwell Nuclear Fuel Plant and near the boundary of the Savannah River Plant (SRP). The site is an irregular polygon covering 121 ha (300 acres) of land measuring roughly 1500 m (4950 ft) in the north-south direction and 750 m (2475 ft) in an east-west direction.

The disposal facility is situated near the eastern edge of the Aiken Plateau portion of the Atlantic Coastal Plain physiographic province. At the site, a layer (approximately 305 m thick) of flat-lying, loose to poorly consolidated sediments of upper Cretaceous, Tertiary, and Quaternary ages unconformly overlie older, well consolidated Triassic Age sandstones and basalts and Precambrian schist. The subsurface soils at the site are quaternary.

Soils immediately underlying the topsoil (which is basically fuquay loamy sand of a loamy siliceous family) consist of loose to moderately dense fine and silty sands and range in thickness from about 0.6 m to 2.1 m. Underlying this sandy layer is the Miocene Hawthorne Formation, which is about 4.3 to 9.1 meters thick and chiefly consists of embedded sandy clay and clayey fine sand. The late Eocene Barnwell Formation (11.6 - 18 m thick) underlies the Hawthorn, while the early Eocene McBean Formation (14.6 - 35 m thick) underlies the Barnwell. Underlying these are the Ellenton and Tuscaloosa Formations, consisting of sand and gravel with some clay and cretaceous sediments.(44)

The topography at the site is flat to gently rolling with grade elevations averaging 74 to 80 m (243 to 262 ft) above mean sea level (MSL). Local vegetation includes wild grass, scrub oak, and pine.(44)

The climate in the area of the Barnwell site is mild and relatively humid, with mean temperatures ranging from 48°F (9°C) in January to 81°F(27°C) in July. The precipitation averages about 1.19 m(47 in) per year, and ranges from 0.073 m to 1.87 m (1952 - 1972 data). Ice storms and dam aging winds are rare. Measurable snow occurs at approximately 10 years' intervals and usually does not remain for great periods of time. The largest recorded snowfall for the area was 45.7 cm (18 in) over a two day period.(44)

The disposal facility is situated geographically between the Savannah River to the west and the Salkehatchie River to the east. Although the Salkehatchie is the closest river, the site is contained in the surface drainage area of Lower Three Runs Creek, which is a tributary of the Savannah River. Flow into Lower Three Runs Creek is controlled by a fixed weir system in Par Pond, which is located on the adjacent Savannah River Plant. Although an evaporation pond exists on the disposal site (but not near the disposal area), there are no surface streams on-site. The nearest sepage point is Mary's Creek 0.914 km to the south.(44)

The groundwater table at the site is contained within the Hawthorn Formation and ranges in depth from about 9.1 to 18 meters with a mean of about 12.2 meters. Fluctuations in the water table are a function of locally varying soil permeabilities and the inclination of the piezometric surface. Water from the underlying Tuscaloosa Formation, however, forms the principal source of potable water for the site area. Water from the Tuscaloosa Formation is generally soft, acidic, and low in dissolved solids. Consequently, water from the Tuscaloosa is corrosive to most metal surfaces.(44)

3.4.2 Disposal Experience

Background

Waste disposal was initiated at the Barnwell site in 1971. During the first year of operation, approximately 12,405 m^3 (49,600 ft^3) of waste containing 4200 Ci of byproduct material was accepted and disposed. The disposal rate rose steadily over the next nine years to the point where the annual rate reached 63,862 m^3 (2,255,000 ft^3) in 1979. Due to restrictions on the annual volume of waste received, however, the disposal rate in 1980 was reduced to about 53,800 m^3 (1,900,000 ft^3). Through 1980, over 323,560 m^3 (11,424,900 ft^3) of waste containing 1,665,100 Ci of byproduct material radioactivity has been disposed. In addition, 5,647,000 lb of source material and 1121 kg of special nuclear material have been disposed through 1980. Transuranic-contaminated waste in concentrations exceeding 10 nCi/gm have never been accepted for disposal at the site.

Two types of disposal trenches have been employed at the Barnwell facility: slit trenches and "standard" shallow land burial trenches. Each of the two slit trenches that have been constructed at the site measure about 76 to 152 m (250 to 500 ft) long, 1 m (3 ft) wide, and 6 m (20 ft) deep. A map of the disposal area is shown in Figure 3-10.

The slit trenches have been used in the past for disposal of waste material having high surface radiation levels such as non-fuel bearing reactor core components (poison curtains, control rods, and other miscelaneous core hardware), with the intention of reducing occupational exposures. Use of the slit trenches has been discontinued and may be replaced by alternative disposal methods to reduce occupational exposures associated with handling waste packages having high surface radiation levels. Most of the waste received at the site has been disposed in the "standard" trenches. These trenches were initially relatively small but more recent disposal trenches are larger,

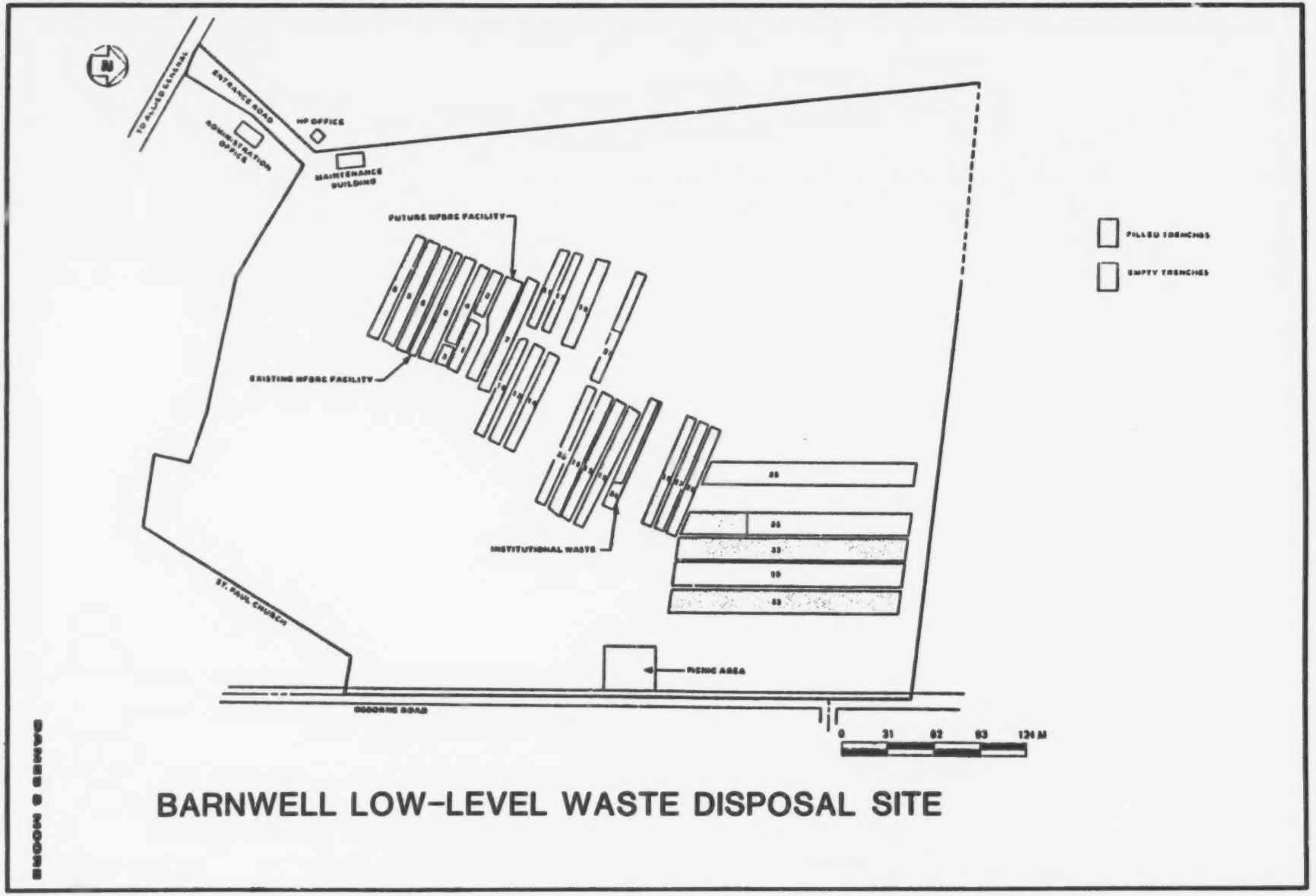

N
10 ALLIED CANAL
ENTRANCE ROAD
ADMINISTRATION OFFICE
NP OFFICE
MAINTENANCE BUILDING
FUTURE NFSRC FACILITY
EXISTING NFSRC FACILITY
INSTITUTIONAL WASTE
ST. PAUL CHURCH
PICNIC AREA
OSBORNE ROAD
FILLED TRENCHES
EMPTY TRENCHES
0 31 62 93 124 M
BARNWELL LOW-LEVEL WASTE DISPOSAL SITE
BARNES & MOORE

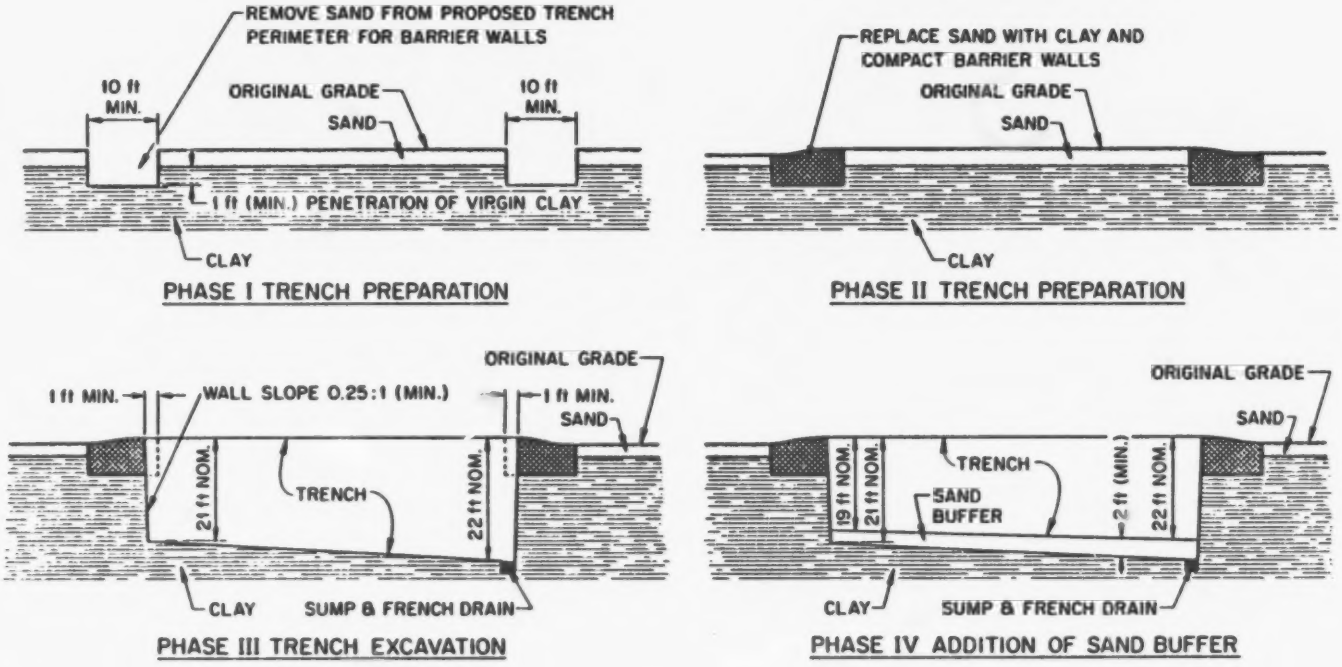
FIGURE 3-10

typically measuring 305 m (1000) ft long by 30 m (100 ft) wide.[44] Somewhat smaller trenches (500 ft by 50 ft) are also occasionally used. A diagram of a typical trench construction sequence is provided as Figure 3.11.

When constructing the disposal trenches, the top few feet of sandy surface soil is first stripped off and replaced with a layer of compacted clay. This is to prevent lateral infiltration of precipitation into the disposal trenches. The trenches are then constructed and the locations of the trench corners surveyed and referenced to a benchmark. Each floor is constructed with an approximate 1 percent slope to one side, where a gravel-filled French drain is constructed which runs along the entire side of the trench. The French drain is also sloped at about 0.3 percent end-to-end to allow drainage of water to a sump which is placed every 500 ft along the length of the trench. A standpipe is placed into the trench sump and also at 100 ft intervals along the length of the trench. Each trench is inspected at least three times by State health department inspectors prior to waste emplacement.[45]

Prior to waste emplacement, two or three feet of pervious sand is placed on the bottom of the operational trench. This is to ensure drainage of water away from the bottom layer of disposed waste packages, to allow unimpeded drainage to the French drain, and to provide a smooth working foundation for waste emplacement.[45] Waste emplacement then commences at the high end of the trench floor, allowing rainwater to drain away from the emplaced waste packages. License conditions prohibit emplacement of waste more than 100 ft beyond the backfilled portion of the trench, and also prohibit emplacement of waste in standing water.[47] Small berms around the edges of the trenches are used to prevent surface water flow into open trenches.

In practice, waste emplacement is a combination of stacked and random disposal. Boxes and ion exchange liners are typically stacked while



BARNWELL DISPOSAL TRENCH CONSTRUCTION TECHNIQUE

FIGURE 3-11

BAMES & MOORE

drums and other small waste packages are typically dumped into the spaces alongside the stacked waste. The disposal facility operators impose economic penalties on waste packages that do not conform to standardized sizes and dimensions.[48] The use of standardized waste packages helps to improve efficient use of trench volume reduces waste container handling times and helps to reduce voids between waste packages. Stacked disposal also helps to reduce voids between waste packages.

After waste emplacement, the trench is backfilled with a sandy soil and the backfill is compacted using a mechanical vibratory compactor. The sand backfill flows into spaces between waste containers and also helps to promote drainage of infiltrating rainwater away from disposed waste. A minimum of 0.6 m (2 ft) of compacted clay is then emplaced, followed by at least 1 m (3 ft) of earth (usually 5 - 10 feet). The trench covers are then graded to promote drainage, top soil is added, and the surface is seeded with grass and fertilized. The ends of each trench are marked with granite markers, as are the four corners.[45]

An extensive health physics program exists at the site, as does an extensive environmental monitoring program. Incoming waste shipments are given a detailed inspection for compliance with NRC and DOT transportation regulations and disposal license conditions. Transport vehicles and personnel are checked for contamination prior to exiting the site. For sole use vehicles, if observed contamination levels are greater than 0.5 mrem/hr or 2200 dpm/100 cm^3, the vehicle is retained and decontaminated. These levels are one-tenth of that prescribed by DOT regulation. If a vehicle is to be released for unrestricted use, it must be decontaminated to background levels. Maximum contamination levels for vehicles, personnel, and site grounds are specified by license condition, which facilitates inspection by regulatory personnel.[46] As a result of the above, there have been no problems at the site with extensive site surface contamination.

To help ensure minimal site and equipment contamination, help reduce occupational exposures, improve transportation safety, and reduce potential migration of radionuclides, a number of requirements have been implemented on waste form and packaging.[47] For example, some of the requirements imposed by license condition include:

- a prohibition on receipt and disposal of toluene, xylene, dioxane, scintillation liquids, or other organic liquids with similar chemical properties;
- a prohibition on receipt of liquid waste;
- a limitation on the quantity of free-standing liquids allowed within waste packages;
- a requirement that any free-standing liquids be noncorrosive;
- a requirement that ion exchange resins and filter media containing radionuclides having half lives exceeding five years and having specific activities of all these radionuclides exceeding 1 uCi/cm^3 must be stabilized. Stabilization may be achieved either through solidification or use of a high integrity container;
- packaging requirements for biological wastes which specify, among other criteria, double containment.

Although not a license condition, the site operator has also prohibited waste packaging in cardboard or fiberboard containers.[48] This is to reduce transportion impacts, help reduce occupational exposures, and help reduce waste compression and subsidence.

Problems Encountered

Since the disposal facility was opened in 1971, there have been no significant problems with operation of the site. There have been, however, numerous instances at the Barnwell as well as the Richland, Washington and Beatty, Nevada sites in which wastes arriving at the site have been packaged and transported in violation of Department of Transportation (DOT), NRC, and Agreement State regulations. For

example, during a package inspection program at the Barnwell site, 43 shipments with 63 deficiencies were observed between April 10 and July 5, 1979. The shipments were from reactor, medical, industrial, and military facilities.[49] (See sections 3.5 and 3.6 for information regarding waste transportation violations at the other two sites.)

These incidents were of concern to the Governor of South Carolina, as well as the Governors of Washington and Nevada, especially since there did not appear to be anyone at either the State or Federal level that actively engaged in enforcing transportation regulations. The three Governors consequently demanded that the Federal Government -- particularly NRC -- take action in this regard. In responding, NRC greatly increased inspections of licensed waste generators and collectors and sent bulletins to licensees. In addition, under an agreement with DOT, NRC regulations were modified in November 1979[50] to incorporate DOT transportation regulations into NRC regulations. Guidelines for enforcement of the new NRC regulations, including establishing severity levels for violations, were issued a month later.[51]

In addition, the Governors of Washington, Nevada, and South Carolina adopted a compliance certification plan which included the following provisions:

- Any person who generates or packages commercial low-level radioactive waste shall be required to provide to the state of destination a Compliance Certificate, warranting that the shipment was inspected within 48 hours prior to shipment and conforms to all Federal and state requirements for shipment,
- Any broker shipping and/or transporting commercial low-level waste, is required to conduct an external visual and dose rate inspection within 48 hours of shipment,
- Any carrier shall give the state at least four but not more than 48 hours notice in writing of the intended movement of the waste material to the disposal site.

Additionally, the certification plan stipulates improvements in

state-run inspection and enforcement programs and establishment of an interstate agreement whereby any LLW originator, broker, or carrier violating the terms in one state would be denied right of shipment to disposal facilities located in the other two states.

3.4.3 Discussion

Although there have been no significant problems with performance of the disposal facility, since operations started a number of changes and improvements to site operations have been implemented in response to experience at the Barnwell and other sites. A number of amendments (about 30) to the conditions contained in the State license have been implemented,[46] and today the facility license is one of the most detailed of the six commercial sites.[47] This allows for more comprehensive inspections by regulatory personnel. In addition, most operations are now covered by detailed written procedures.

Many of these improvements have involved operational procedures, including methods of disposal trench construction, health physics, and environmental monitoring. An example of an improvement in disposal trench construction implemented since operations began is the current practice of replacing the top few feet of sandy surface soil with compacted clay. Many of the waste form and packaging requirements implemented at the site have been imposed within the last few years and are intended to help improve transportation safety.

A number of institutional improvements have also been implemented. For example, recordkeeping has been greatly improved. Manifest documents are required on each shipment of waste. The information contained in the manifests -- including waste volumes, waste type, contained radionuclides and concentrations, location of emplacement within a trench, state originating the waste shipment, and so forth -- is maintained in a computerized data storage and retrieval system. As another example, the level of State regulatory involvement with site

operations is significant. A full-time on-site inspector works at the site, who spot-checks incoming shipments and manifest documents and carries out physical surveys of site operations. The State also carries out independent environmental monitoring activities. Costs for State regulatory activities are largely charged to the site operator.

Perhaps the most significant improvements in institutional requirements have been the adoption into both the State and NRC license of more specific requirements on site closure. These requirements include development by the site operator of a preliminary closure and stabilization plan based upon performance objectives contained in the NRC Low-Level Waste Licensing Branch technical position on site closure and stabilization.[52] Such a preliminary site closure and stabilization plan has been prepared and submitted to the State and NRC.[45] The plan is to be reviewed by the State and NRC at least at five year intervals. A final version of the plan will be reviewed and approved prior to implementation. A requirement that adequate funding arrangements for closure and long-term care be made is also part of the closure license conditions. In regard to long-term care funds, like most sites these are collected as a surcharge on received waste volumes and subsequently placed into an interest-bearing fund. When the site was opened, the surcharge was only $\$0.08/ft^3$. Since then the site lease has been modified for periodic reevaluation. The surcharge is currently up to $\$1.00/ft^3$.[46]

3.5 Richland, Washington

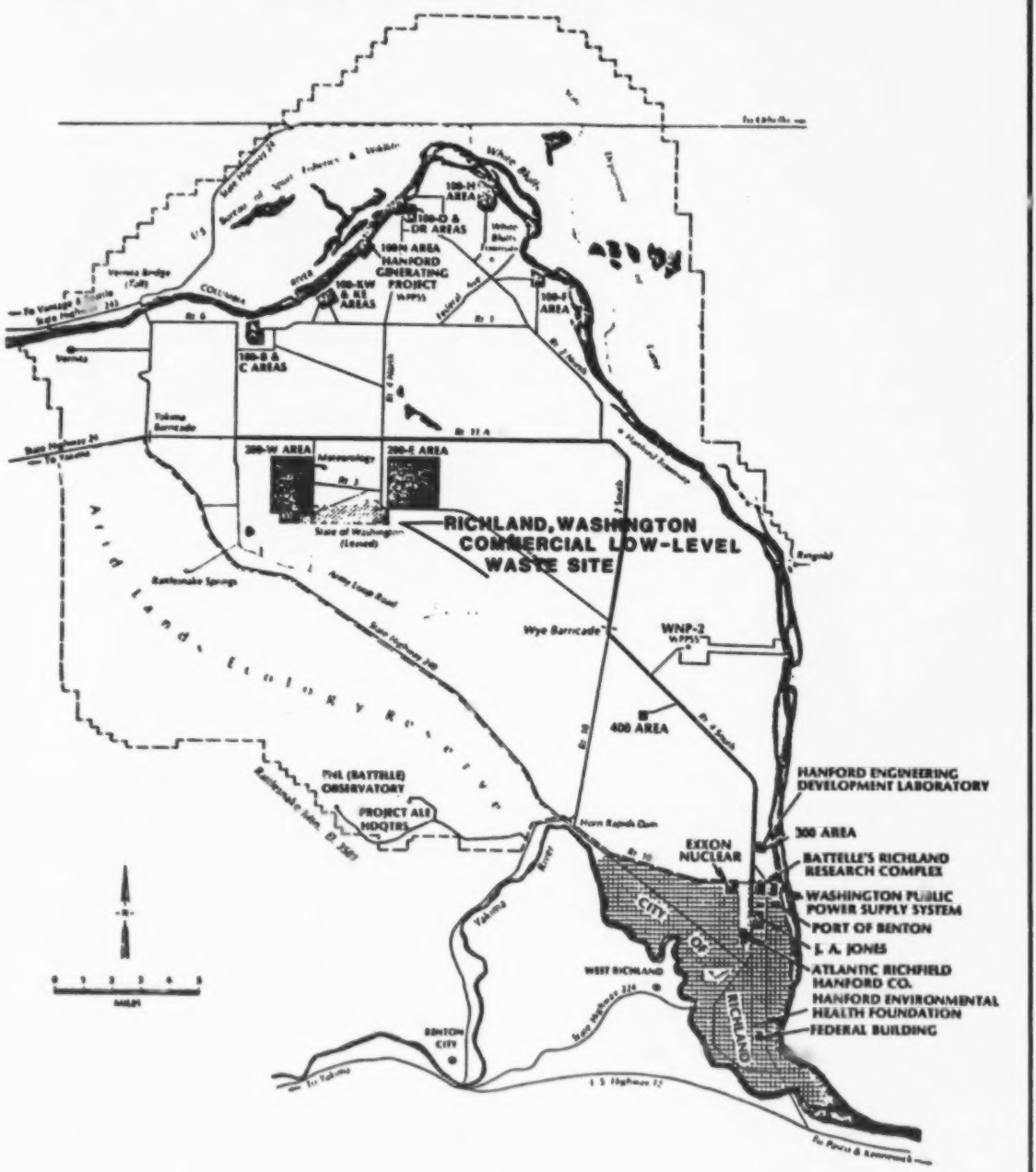
In 1964, the AEC leased 400 ha (1000 acres) of land within the Hanford Reservation (See Chapter 4) to the state of Washington for regulated commercial use. (Currently, DOE acts as the lessor.) The State then subleased 40 ha (100 acres) of this tract to California Nuclear, Inc. the first licensed operator of the site. The site was operated by

California Nuclear from September 1965 until March 1968 when the assets of this company were transferred to the Nuclear Engineering Company (NECO). In 1981, NECO changed its name to U. S. Ecology, Inc. (USE), and is the present licensed operator of the site. The location of the site on the Hanford Reservation (HR) and a layout of the disposal site are shown in Figures 3-12 and 3-13.

The activities at the site were originally licensed solely by the AEC. Washington became an Agreement State on December 31, 1966 however, and the State subsequently took over most of the licensing responsibilities. Currently, the State licenses possession and disposal of source and byproduct material, while NRC licenses possession and disposal of special nuclear material. The site operator, however, has not accepted special nuclear material for disposal since renewal of the NRC license in November 1979.

From 1976 to 1979, the Richland disposal facility was the only commercial facility accepting transuranic waste for disposal. However, this practice was ended by State and NRC license condition in November 1979.

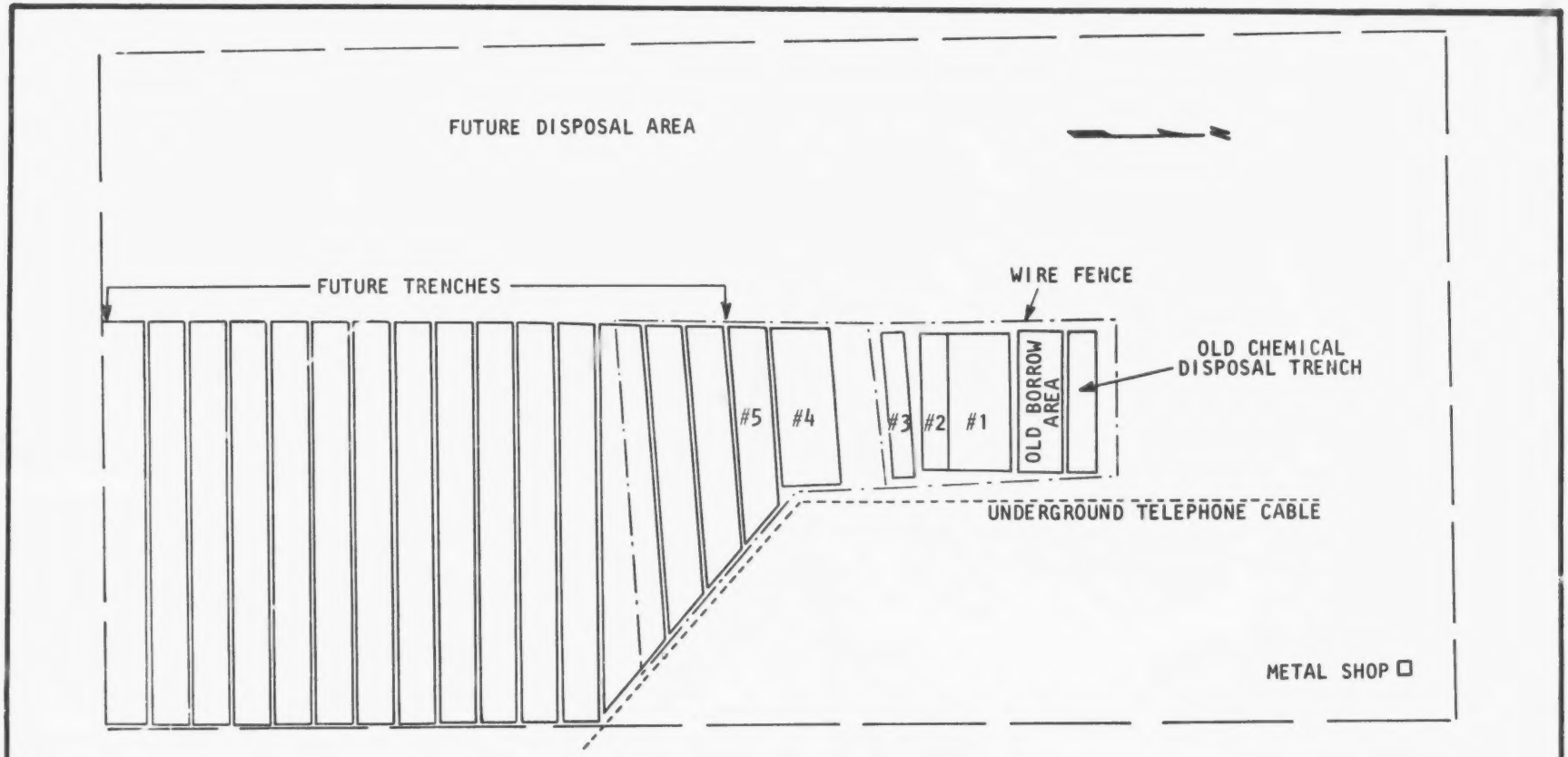
The facility is currently open, although it was closed for a brief period in 1979 following arrival at the site of some improperly packaged radioactive waste packages. Since that time a transportation compliance certification plan has been adopted by Washington (and other states). In 1980, an initiative was passed in Washington which after July 1, 1981 would have prohibited disposal within Washington of waste, other than medical waste, generated outside Washington. This initiative was subsequently challanged and in June 1981, the Circuit Court ruled it to be unconstitutional. This ruling has been appealed to the 9th Circuit Court of Appeals and hearings are expected in the Spring of 1982. The site has continued to accept all types of waste pending the outcome of appeals.



RICHLAND, WASHINGTON
LOW-LEVEL WASTE DISPOSAL SITE

DAMES & MOORE

FIGURE 3-12



RICHLAND, WASHINGTON
COMMERCIAL LOW-LEVEL WASTE DISPOSAL SITE

0 100 200 300 400

SCALE IN FEET

DAMES & MOORE

FIGURE 3-13

3.5.1 Site Environmental Characteristics

The geology, climate, and hydrology of the Hanford Reservation (HR) are summarized in Chapter 4 of this report. Within the Hanford Reservation, the site has an average elevation of 730 ft above mean sea level, and slopes approximately 10 feet from the north site boundary to the south site boundary. The site topography is typical of the central plateau of the Hanford Reservation. Except for areas graded during past or present operations, the surface of the site is almost flat and is covered with dunes to 10 feet high, semi-fixed by desert vegetation. There are no water bodies on or near the site.[53-55]

3.5.2 Disposal Experience

Background

Between September 1965 and the end of 1980, approximately 61,740 m^3 (2.18 million ft^3) of waste containing over 950,000 Ci of byproduct material was disposed at the site. Through the end of 1980, the quantities of disposed source material, special nuclear material, and plutonium measured 64.184 kg (141,500 lbs), 121.43 kg, and 36.53 kg, respectively.[1]

The radioactive waste delivered to the site has principally been disposed by conventional shallow land burial techniques, although as discussed below, some minor variations have been practiced. The trench dimensions have varied, with earlier trenches being relatively small and shallow and later trenches constructed to much larger dimensions. Trenches 1 through 6 typically ranged from 91 to 122 (300 to 400 ft) long, 18 to 43 m (60 to 140 ft) wide, and 8 to 9 m (25 to 30 ft) deep. Larger dimensions are anticipated for future trenches (eg, lengths of 260 m or greater and depths of 11 m or deeper). Spatial arrangement of the trenches is in parallel, with the long axis

of the trenches running east and west. The trenches are separated by about 3 m (10 ft) of space.[55] In constructing the trenches, an attempt is generally made to achieve near-vertical walls. Due to the loose character of the sand and silt soils on the Hanford Reservation, local slumping of the trench walls frequently occurs.

After the waste has been placed into a trench, the sandy and silty soil originally excavated from the trench is used as backfill and final cover. License conditions require that after completion of each trench, the final cover be at least 0.9 m (3 ft) near the edges of the trench and at least 1.5 m (5 ft) along the centerline.[56] However, additional soil is generally used to mound over the trench to help compensate for possible later consolidation of the waste. The surface is then covered with a layer of gravel and cobbles for protection against wind erosion.

Variations to the "conventional" shallow land burial trenches have included caissons and a solar evaporation facility for liquid waste. The caissons have been used in the past (and may be used in the future) for disposal of high exposure rate waste material and are located between Trenches 3 and 4. The caissons consist of four 30 ft vertical wells, 24 inches in diameter. The well liners are made of culvert steel pipe and rest on eight inch thick concrete pads. The wells are at least six feet apart and are covered by a stepped concrete plug while the well is in use. After filling the well, a concrete cap is poured and allowed to harden.[57]

The evaporation facility was used at one time in the past for disposal of low activity liquids and wet wastes such as spent ion exchange resins. Current license conditions prohibit the shipment of liquids to the site, except for liquid scintillation vials. The facility consists of three underground tanks with a capacity of 16,000 gallons each. Each tank has a system to draw hot dry desert air into the underground tanks (through a system of risers) and exhaust the air

through a high efficiency particulate air (HEPA) filter. Higher evaporation rates could be obtained through supplementary heaters. As the water is evaporated, a layer of sludge builds up in the bottoms of the tanks.(57) The evaporation facility has not been used for several years and any residual water has been allowed to evaporate.

The site wsas also briefly used for disposal of chemical wastes. The chemical waste trench contains about 17,000 ft^3 of waste and is located about 120 feet north of radioactive waste disposal trench no. 1. Receipt and disposal of chemical waste ended in June 1970.(55)

Significant updates to the NRC and State licenses occurred in November 1979, when these two licenses were renewed. As part of the November 1979 renewal, a number of waste form and packaging requirements were implemented as license conditions for specific types of waste. These more specific waste form and packaging requirements were intended to further improve transportation and on-site operational safety. Other new license conditions involved updating site procedures for operational health physics, trench construction, and other matters. More specific criteria were also implemented regarding disposal facility closure and stabilization.(56)

Many of the new requirements on waste form and packaging are similar to those imposed at the Barnwell facility. These include a prohibition on receipt of liquid waste and a limitation on the quantity of free-standing liquids allowed within waste packages. Any free-standing liquids must furthermore be noncorrosive. In addition, ion exchange resins and filter media containing radionuclides having a total specific activity of 1 Ci/m^3 or greater of materials with half-lives greater than 5 years must be stablized either through solidification or use of high integrity containers. Other packaging requirements include a prohibition on use of cardboard, fiberboard, and paper packages, as well as a requirement that all wooden boxes be banded with metal bands. Since the Richland site is in a very arid

environment, scintillation vials and fluids, in vitro units, and other medical wastes are accepted at the site. However, packaging criteria specifying double containment of waste are imposed for these wastes as well as for animal carcasses and other biological wastes.(56)

In addition to setting up an inspection and reporting system for waste received at the site, other new license conditions cover waste emplacement and trench construction. For example, wastes containing chelating agents in amounts greater than 1 percent of the package volume are required to be disposed in a segregated manner from other wastes. Wastes which exceed Type A quantities (as defined by DOT transportation regulations) must be disposed at greater depths, as do wastes having high surface radiation levels.(56)

The license requires the boundaries of disposal trenches to be fixed by engineering surveys and referenced to a benchmark. In addition, license conditions require than a minmum of 2.4 meters (8 ft) separate the top of the disposed waste and the original ground surface. This is consistent with DOE practice at the surrounding Hanford Reservation, greatly reduces the potential for intrusion by burrowing animals and insects, and to a lesser extent reduces the potential for intrusion by deep-rooted plants such as tumbleweeds. It also helps to minimize the effects of possible subsidence and settling, as well as greatly reduces potential impacts of wind erosion. (The requirement of the eight foot spacing is also one of the reasons that the site operator has been constructing trenches to greater depths.) To further reduce the potential for wind erosion or intrusion by burrowing animals, the thickness of the gravel and cobble layer over the completed trenches has been raised to a minimum of 6 inches.

Other license conditions set out more detailed requirements for operational health physics and environmental monitoring. For example, site contamination limits for transportation vehicles and site grounds are specified, as are inspection frequencies. A minimum environmental

monitoring program is specified, and recordkeeping and reporting requirements for the health physics and environmental monitoring programs are also specified. Other recordkeeping requirements include whose for incoming waste shipments and site maintenance activities.

Problems Encountered

In October 1979, the Washington Governor temporarily shut-down the disposal site because of irregularities with shipments bound for the site. The transportation deficiencies reported included the following:[58] (1) a leaking shipment of radiopharmaceutical cobalt, (2) a shipment of contaminated scrap metal losing some of its dunnage (packaging material), and (3) an overweight load containing depleted uranium. These occurrences and the subsequent shut-down order were not related to deficiencies in the performance of of the disposal site, but rather a reaction to loosely enforced Department of Transporation (DOT) regulations. The Richland site was reopened in late November of 1979 following assurances of appropriate action by Federal regulatory agencies and the adoption of a compliance certification plan by the Governors of Washington, Nevada, and South Carolina (see Section 3.3).

More recently, a state initiative was passed which would have had the effect of closing the site. The critical sections of this 1980 initiative are as follows:

> Section 3 Notwithstanding any law, order, or regulation to the contrary, after July 1, 1981, no areas within the geographic boundaries of the state of Washington may be used by any person or entity as a temporary, interim, or permanent storage site for radioactive waste, except medical waste, generated or otherwise produced outside the geographic boundaries of the state of Washington. This section does not apply to radioactive wastes stored within the state of Washington prior to July 1, 1981.
>
> Section 4 Notwithstanding any law, order, or regulation to the contrary , after July 1, 1981, no person or entity may

transport radioactive waste, except medical waste generated or otherwise produced outside the geographic boundaries of the state of Washington to any site withn the geographic boundaries of the state of Washington for temporary, interim or perminent storage.

Section 6 Notwithstanding the other provisions of this chapter, the state of Washington may enter into an interstate compact, which will become effective upon ratification by a majority of both houses of the U. S. Congress, to provide for the regional storage of radioactive wastes.

Thus the Richland site would have been unavailable after July 1, 1981 for the disposal of many types of low-level waste. The only waste that would have been clearly acceptable would have been medical waste. This initiative was challanged by the Department of Energy (and others) and on June 26, 1981, the Circuit Court ruled that the referendum was unconstitutional. The ruling has been appealed to the 9th Circuit Court of Appeals. No court date for hearings has been set, but the Attorney General estimates that hearings will be held in the spring of 1982. The site has continued to accept all types of waste pending the outcome of the appeals.(59)

3.5.3 Discussion

As discussed in more detail in Section 4.3, the natural site characteristics of the Hanford Reservation upon which the disposal site is located appear to be quite favorable. These include low annual precipitation rates, high evapotranspiration rates, relatively homogeneous disposal media having high adsorptive capacities, and the relatively long distance to the water table. As a result, there have been no problems with groundwater migration from the site and no problems are expected in the future. In addition, the site is located well above the probable maximum flood level for the Reservation.(53) Potential long-term problems with wind erosion of site soils have been greatly mitigated and possibly eliminated through engineering means -- i.e., by the large thicknesses of earth placed over the disposed

waste and the license requirement for trench stabilization against wind erosion.

The problems that have been experienced at the site are unrelated to the operation of the site or to the ability of the site to contain radioactive waste, but are a result of violations of transportation regulations by waste shippers and transporters. As discussed above, these violations led to the transportation compliance certification program. Many of the license conditions implemented as part of the November 1979 license renewal are intended to further improve waste transportation safety.

The current license for the site is very detailed, containing specific requirements on waste form, operational health physics, trench construction, etc. which can be inspected against. Perhaps most importantly, the site license contains specific requirements on preparation for site closure. Similarly to the Barnwell site, the site operator is required to prepare a preliminary site closure and stabilization plan addressing site closure, the conditions of the site upon transfer to the site owner, and arrangements for funding for closure and long-term care. Such a preliminary site closure plan has been prepared by the site operator.(60)

3.6 Beatty, Nevada Site

The Beatty, Nevada disposal facility was licensed by the U.S. Atomic Energy Commission (AEC) in 1962, making it the first licensed commercial disposal site. The facility is located near Highway 95 in the Amargosa Desert close to the Nevada Test Site about 11 miles south-southeast of the town of Beatty and 100 miles northwest of Las Vegas.

The site, owned by the State of Nevada, consists of a 32.4 ha (80 acres) leased tract and is currently operated by U. S. Ecology, Inc. (USE) of Louisville, Kentucky. It is on lease to USE for a period of

99 years which commenced on September 5, 1962. A non-radioactive chemical waste site, on the 80 acres and immediately adjacent to the LLW disposal site, is also operated by USE. It is separated from the LLW disposal site by a buffer zone about 400 feet wide.[46,61,62]

In 1972 the AEC (now the NRC) transferred the primary responsibility of licensing and regulating activities at the site to the State of Nevada, which became an Agreement State at that time. Under this arrangement, the State of Nevada regulated possession and disposal of source and byproduct material, while AEC regulated possession and disposal of special nuclear material (SNM). The NRC continued to license disposal of special nuclear material at the site until 1977, at which time this license was terminated. Currently, all activities at the site are regulated by the State of Nevada.

The disposal facility is currently open. For reasons unrelated to the long-term ability of the site to contain radionuclides, however, its future is somewhat in question.[46] As discussed below, the disposal facility has been closed on several occasions over the past five years.

3.6.1 Site Environmental Characteristics

The disposal site is located in Nye County, Nevada, in the Amargosa Desert in Section 35, Township 13 South, Range 47 East, at the Mount Diablo Baseline and Meridian. The Amargosa Desert is part of the Basin and Range Physiographic Province which is generally characterized by relatively barren mountain ranges separated by broad, relatively flat valleys. The valley floor in the Amargosa Desert is composed of unconsolidated deposits of clay, silt, sand, and gravel. This material has been derived from the weathering of the adjacent mountain ranges and hills. The thickness of the valley fill is estimated to be at least 175 m (575 ft) thick.[61]

The bedrock below the valley fill is probably comprised of rocks similar to those exposed at Bare Mountain (located near the town of Beatty, Nevada). The rocks comprising Bare Mountain are a structurally complex assemblage of Paleozoic metamorphic and sedimentary rocks and of volcanic rocks of the Tertiary age. The ground surface elevation at the site ranges approximately 844 to 850 m (2770 to 2790 ft) above mean sea level. The area surrounding the site slopes gently toward the south and southeast at a rate of approximately 6 to 8 m per km (30 to 40 feet per mile). Site topographic surveys indicate that the average slope ranges from 1:100 to 1:200.(61)

The average rainfall at the site ranges from 63.5 to 127 mm (2.5 to 5.0 in) per year. The rainfall total during some years is less than 25 m, yet, occasional annual totals exceeding 250 mm can be expected (Ref 1). The annual evaporation at the site has been estimated to be approximately 2540 mm (100 in).(61)

The principal drainage channel in the area is the dry bed of the Amargosa River. In the hills north of the town of Beatty, some perennial flow is maintained in the Amargosa River by springs; however, perennial flow dose not exist within 16 km (10 miles) of the disposal site. The regional water table is believed to be located about 99 m (325 feet) below the ground surface.(61)

3.6.2 Disposal Experience

Background

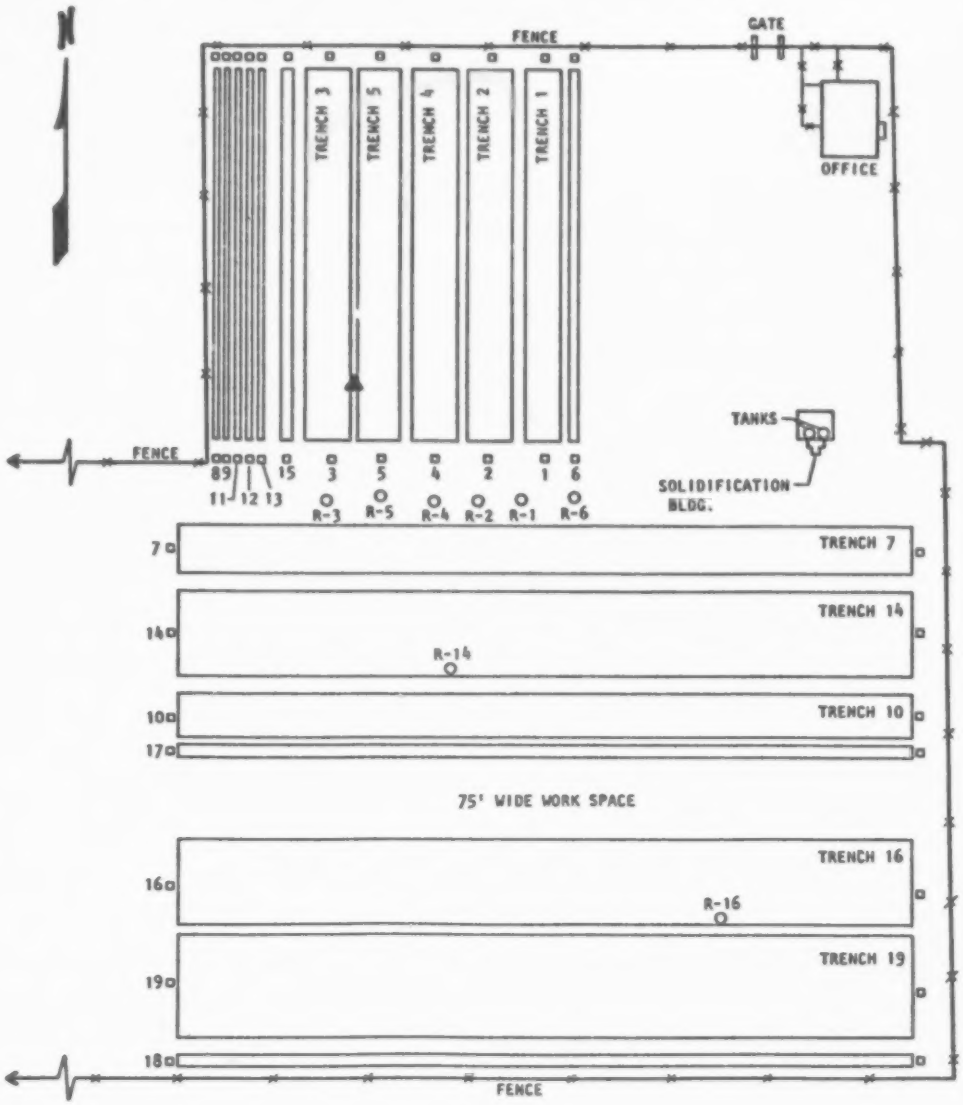
Through 1980, a total of nearly 3.2 million cubic feet of waste has been disposed at the Beatty facility (see Appendix A for annual volumes of waste). This waste has contained approximately 458,500 curies of by product material, 363,000 kg (800,900 lbs) of source material, 218 kg of special nuclear material, and 14.29 kg of plutonium.(1)

LLW has generally been disposed at the site by means of a cut-and-cover trench operation. The trench cutting and cover operation is accomplished by means of heavy equipment such as pan-scrapers and bulldozers. Trenches are cut with nearly vertical (>75^{0}) side slopes. Waste emplacement is accomplished by means of a crane and forklift as well as by hand. The trenches are frequently long and wide enough so that transport vehicles may be driven down ramps and directly into the trenches for unloading. The operating license requires a minimum of 0.9 m (3 ft) between the top of the buried waste and the ground surface. Additionally, the trench cover must be mounded so that the center line of the trench cover is at least 0.6 m (2 ft) above the existing ground surface.(63)

To date, twenty-two trenches have been used at the site for radioactive waste disposal (Figure 3-14). A summary of trench dimensions and contents of the first nineteen trenches, as compiled from the trench monuments during a site visit, is provided in Table 3-4.(62) The trench dimensions have ranged from 91 to 200 m (300 to 650 ft) in length, 1.2 to 27 m (4 to 90 ft) in width and 1.8 to 6 m (6 to 20 ft) in depth. More recently, the dimensions of the disposal trenches have greatly increased. For example, the dimensions of trench 22, which is the current operational trench, are about 800 ft long by 305 ft wide by 50 ft deep.(46) Prior to use, the boundaries of each trench must be surveyed and depicted on a scale drawing of the site.(63)

Problems Encountered

In March 1976 an investigation was initiated by the Nevada State Department of Human Resources to ascertain the extent to which violations of the site license had occurred. This investigation was a result of a report by NECO, the site operator. In the report to the State, NECO informed the State that a site cement mixer normally used for the solidification of low-level liquid radioactive waste had been used off-site to pour concrete slabs at several local properties.(14)



BEATTY LOW-LEVEL WASTE DISPOSAL SITE

0 50 100 150 200

SCALE IN FEET

KEY:

7 □ TRENCH MONUMENT

R-3 ○ OBSERVATION WELL

DAMES & MOORE

FIGURE 3-14

TABLE 3-4 . Beatty Low-Level Radioactive Waste Disposal Site Inventory (by Trench)

Trench Number	Dimensions (feet) L	W	D	Volume (cubic feet)	By Product Material (Curies)	Special Nuclear Material (grams)	Source Material (pounds)
1	300	31	20	49,692	144	107	20
2	300	40	20	86,788	1,909	1,545	1,070
3	300	40	20	97,453	7,903	8,280	3,450
4	300	40	20	65,120	4,323	2,742	2,971
5	300	40	20	65,120	2,945	10,329	1,525
6	300	4	6	1,840	4,067	0	0
7	650	40	20	206,781	10,353	26,616	7,360
8	300	4	6	2,160	4,320	0	0
9	300	4	6	844	2,996	97	1
10	650	40	20	311,109	928	22,054	1,934
11	300	4	6	406	3,137	125	12
12	300	4	6	322	1.175	0	0
13	300	4	6	384	3,403	0	0
14	600	70	20	400,458	7,986	35,128	0
15	300	10	10	581	5,007	656	0
16	600	75	20	330,994	20,943	35,531	13,063
17	650	10	6	510	1,809	881	0
18	650	10	6	1,087	2,364	903	0
19	650	90	30	457,332	35,525	44,673	42,921
Totals				2,078,971	121,237	189,667	74,327

Source: Reference 62

During the investigation performed by the State, evidence of other violations were revealed which had occurred over a several year period. These violations included the removal of contaminated tools, equipment, and supplies from the Beatty site by NECO employees. These items include radium gauges and dials laboratory equipment, and empty waste containers. After reporting its findings to the U.S. NRC, the State suspended the NECO license to operate the disposal site on March 8, 1976. Several days later, the NRC suspended its license with NECO to accept and dispose of SNM.(14)

A thorough investigation by the State, ERDA, NRC, and U.S. EPA ensued. The follow-up investigation revealed that the contaminated materials had been distributed through the town of Beatty. The study revealed that no significant exposures were experienced by any recipients of the diverted material. Contaminated material that was identified during the investigation or turned in by the citizens was returned to the site and disposed.(14)

The Nevada Department of Health and Welfare lifted the order which had suspended NECO's State license to operate the disposal site on May 25 1976. The suspension order was based on a declaration of emergency conditions resulting from the diversion of the waste material. Once it was demonstrated that there was no significant hazard to the public health and safety, the suspension order was lifted on the basis that the emergency conditions had abated.(14) As part of reopening the site, however, a number of new license conditions were imposed on the State license intended to improve management control over site operations and to provide safeguards against further repetitions of waste diversion. The lease with the site operator was also renegotiated. The NRC special nuclear material license remained suspended until it was terminated by NRC. The NRC license termination was coordinated with the State, who amended their license with NECO to include possession of small quantities of special nuclear material. This concurrent action allowed the site operator to possess unburied

special nuclear material in less than critical quantities and transuranics (TRU) in concentrations less than 10 nCi/gm.[64]

In July of 1979, the Governor of Nevada ordered the site to be shut down after two major incidents were reported in a two month period. In the first incident, a truck carrying improperly packaged radioactive medical waste caught fire at the disposal site. In the second incident, a truck loaded with what was supposed to be solid waste (dewatered resins) from a nuclear power plant arrived at the site leaking contaminated liquids.[58] A number of other incidences of leaking packages as well as less significant violations of Federal transportation regulations such as improper placarding or improper shipment manifests were also recorded.

No significant site or personnel contamination or off-site releases occured from these events. The former Director of the Department of Human Resources has described all of the incidents as "significant", although he has also stated that at no time was the health and safety of the people of Nevada impacted.[65] However, the events were symptomatic of a general slackness on the part of waste generators and shippers. The State executive department took the position that while the safety of the disposal site and disposal site operations were not in question, the presence of the facility meant that unsafe shipments of LLW would be transported across Nevada's roads and highways. The State contended that since it could not control the waste packagers and shippers and since DOT was not adequately performing its job, the State had no choice but to take action by closing the site.[46]

After shutting-down the site, the Governor of Nevada joined with the governors of South Carolina and Washington in demanding that the Federal government enforce the rules governing shipments of LLW. The governors of these states demanded assurances that a program would be set up to combat shipping and packaging problems. These assurances were given, and the Governor of Nevada allowed the reopening of the

Beatty site in late July, 1979. A permitting system for use of the site was set up in a similar manner as the system at the Richland and Barnwell sites.

In October 1979 during a subsurface investigative program by the U.S. Geological Survey (USGS) at the Beatty site, several waste drums were discovered below the ground surface outside the fence surrounding the disposal trenches. They were, however, on the site property controlled by NECO and owned by the State. The Governor of Nevada once again ordered that the site be shut-down.(64) It is probable that these drums were buried near the end of one of the older trenches. Since the coordinates of some of the earlier trenches were not well established and since the fence was installed well after the earlier trenches were completed, the fenceline could have been erected at an incorrect location. The disposal site was reopened in December, 1979.

The operating license for the Beatty facility came up for renewal in June, 1980. An application for renewal of the license was submitted by the site operator to the Radiological Health Section of the Nevada Department of Human Resources. After review of the application, the Radiological Health Section recommended to the Director of the Department of Human Resources that the license be renewed. However, the Department of Human Resources and the State Health Officer subsequently denied renewal of the license, stating that the action is "necessary to protect its citizens from an uncontrollable system of improper packaging and transportation of low-level radioactive waste into the State."(46)

The site operator then requested an administrative hearing before the State Board of Health. The State Board voted to overturn the denial and renew the license for another three years. In its conclusions of law, the Board stated that "there is no evidence of record to sustain the allegation that the packaging and transportation of low-level

nuclear waste to be buried at the Beatty Disposal Site is inimicial to the public health of the citizens of the State of Nevada and that therefore, there is no violation of either Chapter 439 or 459 of the Nevada Revised Statutes nor regulations enacted thereunder."[46] This action by the State Board was blocked on procedural grounds (lack of authority). The Board then ordered the Department of Human Resources to renew the license for three years. The State Attorney General obtained a second stay on procedural grounds and hearings were scheduled in Curcuit Court based on the Attorney General's appeal. Procedural questions were discussed and dismissed on October, 1, 1981. As of early November 1981, a date for the main hearing has not been set. The disposal site has remained open pending the outcome of the hearing.[64]

Following the decision of the Nevada Board of Health, the Department of Human Resources instituted a third-party inspection system which was effective on April 1, 1981. Under the system, all prior permits held by waste generators to use the disposal facility were revoked, and new permits were issued conditioned on acceptance of the inspection system. The inspection system is administered by a State contractor, the Nevada Inspection Service, Inc., (NIS). Generators who wish to ship LLW to Beatty must first undergo an audit by NIS to determine compliance with Federal and State regulations and disposal facility license conditions. If NIS finds the operations to be adequate, the Radiological Health Division may then issue a permit to the generator allowing it to ship LLW to the disposal facility. NIS thereafter makes periodic, surprise inspections of the licensed generators. If shipments are found to not conform to Federal, State, and disposal facility license requirements, the waste generator's permit may be suspended by the State and a fine assessed. In the 1981 Nevada legislative session, the Nevada legislature increased the power of the inspection system by permitting the Health Division to asssess administrative fines of up to $10,000 against the shippers, and assess criminal penalties and fines under criminal statutes against the operator of the site.[46]

The third party inspection system costs each generator $1,000 for the initial inspection and, after the first 100 cubic feet $3.50 for each cubic foot of LLW disposed at the site. In the event of a violation, a waste generator must have all of its shipments inspected for a period of time at a rate of $5.00 per cubic foot or the actual inspection fees, whichever is larger. A result of the third party inspection system has been a drastic reduction in the amount of waste received at Beatty. Current monthly volumes are running around 3,000 cubic feet, as compared to 25,000 to 35,000 cubic feet received in the same months in 1980.[46]

3.6.3 Discussion

The environmental characteristics of the disposal facility appear to be favorable to disposal of LLW. Favorable geologic characteristics include reasonably flat topography and moderate to low primary permeability of the site soils. The low annual precipitation rate (less than 127 mm) at the site, the large depth to groundwater, and the lack of surface water reduces the potential for significant contact between the waste and water. The potential negative natural factors at the site include low long-term resistance to eolian transport of surface soils as a result of sparse vegetation. This can be greatly minimized or eliminated by engineering techniques.

The difficulties that have been experienced are unrelated to the ability of the site to contain radionuclides. The problems with respect to waste diversion from the disposal site were a result of earlier inadequate management control over site personnel that existed at the site at the time the problems were occurring. (Subsequent to the diversion problem, NECO management changed hands, there have been no such diversion problems since.) The problems with waste shipments can be attributed to a large degree to waste generator and shipper practices. The problems associated with the drums discovered outside the restricted area fence may be attributed to earlier recordkeeping and maintenance practices.

In any case, as the site has been operated, a number of license conditions have been added in response to the above problems and to experience at other disposal sites.[63] For example, although liquids in bulk quantities were once received at the site for subsequent solidification and disposal, this practice has been discontined. With some exceptions (eg, some types of medical wastes), receipt of liquids at the site is prohibited. Some of the requirements instituted after the diversion problems included increased security (additional fencing and access control), additional trench construction requirements (including a requirement to survey trench boundaries and reference the surveys to a benchmark), improved record-keeping requirements, a prohibition against opening disposal packages, and a requirement that waste normally be emplaced within three working days of receipt.[63]

Other, more recent requirements are intended to help address the problems with leaky waste packages being delivered to the site. One requirement emphasized that all radioactive material accepted for disposal be in DOT-approved containers. Another requirement prohibited receipt of waste containers constructed of cardboard or fiberboard. (The State later rescinded this prohibition, but the site operator has apparently continued to receipt cardboard or fiberboard containers.) The site operator is also required to notify the State of any shipment lacking manifests and to store such shipments until the contents can be determined, or until otherwise directed by the State. Finally, receipt of liquid radioactive waste solidified in urea-formaldehyde is prohibited. (Waste solidified in urea-formaldehyde frequently exhibits large quantities of free-standing liquids; the pH of the liquids is usually quite low and is therefore very corrosive.)

Updates in institutional requirements have included a State inspector on-site during business hours to observe site activities and to independently check incoming shipments for compliance with transpor-

tation regulations and site license conditions. Unlike the Barnwell and Richland facilities, there are no requirements in the site disposal license for preparing and implementing a specific site closure and stabilization plan. Officials of the State Radiological Health Section, however, feel that this is compensated by a strong lease with the site operator. This lease was renegociated in 1979 and the site operator agreed to post a bond against closure costs. In addition a sinking fund exists for long-term care of the site. This fund is fed through sources such as fines on transportation violators as well as a surcharge on received waste. This surcharge was raised in 1979 from $\$0.13/ft^3$ to $\$0.25/ft^3$.[46]

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4.0 GOVERNMENT DISPOSAL SITES

LLW has been disposed at several government facilities throughout the United States. The largest volumes of waste were disposed at five major national facilities which include. Oak Ridge National Laboratory (ORNL) in Tennessee, Los Alamos Scientific Laboratory (LASL) in New Mexico; Hanford Reservation (HR) in Washington, Idaho National Engineering Laboratory (INEL) in Idaho; and Savannah River Plant (SRP) in South Carolina. Waste disposal has also occurred at several other government facilities which include the Nevada Test Site, the Pantex Plant (Texas), Sandia Laboratory (New Mexico), the Feed Materials Production Center (Ohio), the National Lead Company (Niagara Falls, New York), the Paducah Gaseous Diffusion Plant (Kentucky), the Portsmouth Gaseous Diffusion Plant (Ohio), Oak Ridge Gaseous Diffusion Plant (Tennessee), Oak Ridge Y-12 Plant (Tennessee), Weldon Springs Site (Missouri), and Brookhaven National Laboratory (New York).

The first federal government disposal sites for LLW were at ORNL, LASL, and the HR. Work with nuclear material and subsequent generation of radioactive wastes gained full momentum in 1943 at these three locations. In the early 1950's, the two remaining large defense facilities commenced full scale operations in South Carolina (Savannah River Plant) and in Idaho (Idaho National Engineering Laboratory, formerly the National Reactor Testing Station).

Over three million ft^3 (8.63×10^4 m^3) of LLW is annually generated by the federal government.[1] A large portion of this volume (perhaps as much as half) is suspect waste (i.e., waste, such as paper trash from a research library, which is only suspected of containing radioactivity). The types of waste disposed at the five major federal sites primarily include contaminated trash, process waste, contaminated equipment and materials, and activated metals. The contaminated

trash consists of items such as protective clothing (e.g., gloves and laboratory coats), paper trash, packing material, broken glassware, tubing, plastic sheeting, and animal carcasses. Contaminated equipment contains such items as glove boxes, drain traps, ventilation ducts, shielding, and laboratory equipment. Process wastes include filter cartridges, filter sludges, spent ion-exchange resins, and evaporator bottoms.

The LLW buried at the DOE sites is usually packaged in a variety of containers. Waste containing only small quantities of radioactivity is packaged in plastic bags, metal cans, cardboard boxes, wooden boxes, and carbon steel drums. Tritium wastes may be packaged in asphalt lined or covered containers. Wastes containing intermediate and high quantities of radioactivity are frequently packaged in metal or concrete containers. For higher activity wastes, the package may be designed to provide both biological shielding and some measure of containment following disposal.

The specific histories of LLW disposal sites at government facilities are reviewed below. In addition to a general history and description of the disposal methods employed, the hydrogeologic and meteorologic parameters which positively or negatively affect disposal site performance are briefly discussed. For completeness, brief descriptions of other waste management activities such as transuranic waste storage are also included.

4.1 Oak Ridge National Laboratory (ORNL)

ORNL[2-5] was opened in 1943 to assist in the research and development of Atomic Weapons in support of the Manhattan Project's war effort. The laboratory tract occupies approximately 23,829 ha (58,858 acres) of land and is located within the Valley and Ridge Province in Tennessee.

4.1.1 Site Environmental Characteristics

ORNL is located on a portion of the Valley and Ridge Province characterized by multiple elongated valleys which trend northeastward, and are separated by ridges that are 61 to 152 m (200 to 500 ft) high. The disposal areas at ORNL are located in the Bethel and Melton valleys. The two valleys are separated by a ridge which rises a few hundred feet above them. The Bethel Valley is underlain by limestone while the Melton Valley is underlain by shale. The residuum in Bethel Valley is relatively thin (less than 6 m (20 ft) thick) and is composed of heavy yellow to yellowish-brown clay containing fragments of limestone and chert. The residuum in Melton Valley has an average thickness of 6 m (20 ft) with a maximum depth of about 12 m (39 ft). This residuum is generally composed of yellowish-brown to brown silty clay.

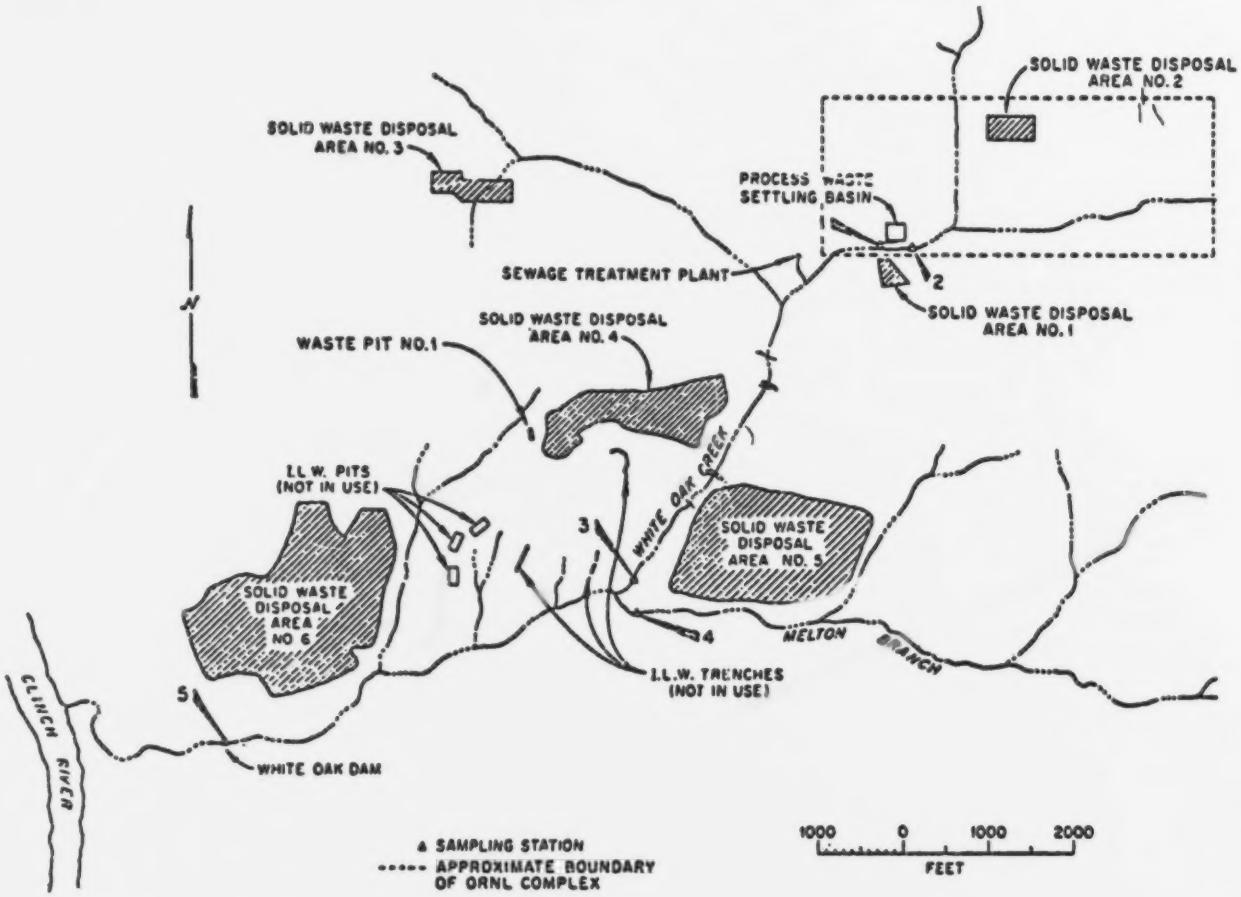
The climate at ORNL is humid. The mean annual precipitation is about 1400 mm (55 in). The potential evapotranspiration rates in the vicinity of the site ranges from about 800 to 900 mm (31 to 35 in).

Depth to groundwater at the ORNL disposal areas ranges from 0 to 20 meters (0 to 66 ft). There is no significant regional aquifer present below the disposal areas. Small perennial streams including White Oak Creek flow through the site. The permeability of the saturated soil zone in the Melton Valley disposal areas is quite low (approximately 0.6 m/day or 2 ft/day). The adsorptive capacity of the soils in the vicinity of disposal areas is relatively high, the cation exchange capacities of the soils range from 5 to 28 meq/100g.[2-5]

4.1.2 Disposal Experience

Background

Radioactive solid waste at ORNL is disposed in trenches, pits, and shafts (Figure 4-1).[2,3,5,6] Typical trench dimensions at ORNL are



OAK RIDGE NATIONAL LABORATORY SOLID WASTE DISPOSAL AREAS

FIGURE 4-1

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3 m (10 ft) wide, 3 to 4.5 m (10 to 15 ft) deep, and 15 m (50 ft) long. Significantly longer trenches were excavated in the past; however, this was later found to be undesirable for the existing environment at ORNL. The total volume of waste accumulated at ORNL through the end of 1979 was 192,400 m^3. This waste is either stored or disposed at the site.

At ORNL, individual sites used for disposal or storage of radioactive waste are termed solid waste disposal areas (SWDA). There are a total of six principal solid waste disposal areas located within the ORNL property. SWDA 1, 2, and 3 are located within Bethel Valley while SWDA 4, 5, and 6 are located in Melton Valley. At the present time, only SWDA 6 is actively used for shallow land burial of radioactive solid waste. Solid waste disposal areas 3 and 5 are used for storage of contaminated equipment and transuranic (TRU) waste, respectively.

Solid Waste Disposal Area-1 (SWDA 1) was used between 1943 and 1944. A total of about 0.6 ha (1.5 acres) of land was employed. SWDA 1 was closed after groundwater was observed in one of the disposal trenches. SWDA 1 lies in the surface drainage path from the adjacent hillside (Haw Ridge) leading to White Oak Creek. Marsh conditions in the low topographic portions of the area may develop following periods of rainfall. The combination of a high water table and unfavorable surface drainage characteristics of this area rendered it undesirable as a solid waste disposal area.

SWDA 2 (occupying about 1.2 ha of land) was used between 1944 and 1946. This solid waste disposal area is located north of SWDA 1 on the opposite side of the X-10 building complex. This location is in close proximity to the waste generating facilities. It was chosen to reduce the waste hauling time, to provide all weather access, and to consume acreage which had low potential for a building site. The characteristics of the buried waste range from construction debris

and waste from temporary sanitation facilities to highly contaminated alpha waste. The groundwater table in the vicinity of SWDA 2 reportedly ranges from approximately 1.5 m (4.9 ft) below ground surface near the base of the hill upon which the site is located to over 9 m (30 ft) in topographically high portions of the site. Minor leachate movement may have occurred at SWDA 2 as evidenced by the removal of a contaminated tree found near the parking lot north of building 4500.

SWDA 3 is also located within Bethel Valley about one-half mile west of SWDA 1, and was used between 1946 and 1951. A total of 2.2 ha (5.5 acres) of land was used for disposal. Both alpha and beta-gamma wastes were disposed at SWDA 3. During earlier years, alpha wastes in drums were deposited in concrete lined trenches at one end of the solid waste disposal area. Later, as the solid waste disposal area extended, alpha wastes were placed directly in unlined trenches and covered with concrete. Beta-gamma wastes were buried in separate unlined trenches and backfilled with the excavated soil. The depth of the trenches generally did not exceed 4.6 m (15 ft). A small intermittent tributary of White Oak Creek runs through the solid waste disposal area. The depth of the water table at SWDA 3 ranges from less than 3 m (10 ft) to slightly over 10 m (33 ft). Some contaminated leachate has been observed at this location.

SWDA 4 is located within Melton Valley adjacent to and west of White Oak Creek. Approximately 9.3 ha (23 acres) of land was employed for waste disposal between February 1951 and July 1959. This area was used for disposal of both ORNL-generated waste and waste from offsite facilities. Beta-gamma wastes were disposed in unlined trenches in the weathered shale and were backfilled with the original soil. Alpha contaminated wastes were disposed in unlined trenches, backfilled with indigenous soil, and capped with approximately 46 cm (18 in) of concrete. Recoverable higher level alpha wastes were placed along the edge of the disposal area in auger holes (frequently capped with concrete) which were about 0.6 m (2 ft) in diameter and approximately 4.5 m (14.8 ft) deep.

SWDA 5 is a 13.4 ha (33 acres) site located about 305 m (1000 ft) east of SWDA 4 on the eastern side of White Oak Creek, and used for both storage and disposal of radioactive waste. The northern section of SWDA 5 is presently used for storage of transuranic (TRU) waste. The southern section of the area was used for shallow land burial of LLW between 1959 and 1973. The southern section is a gently sloping hillside with several small ravines and localized areas of high groundwater table. The ravines, the TRU storage area, and the use of some acreage for hydraulic fracturing facilities, reduces the area actually used for shallow land burial to considerably less than 13.4 ha. At SWDA 5, beta-gamma wastes were buried in trenches at depths of up to 4.6 m (15 feet). Prior to 1971, alpha-contaminated wastes were buried in unlined trenches and backfilled with concrete and soil. Since the AEC directive in 1971 which called for retrievable storage of waste contaminated with transuranics in concentrations greater than 10 nanocuries per gram, TRU waste has been stored in structures at SWDA 5. The trenches at this site range from 12 to 152 m (40 to 500 ft) in length and were generally excavated lengthwise in a direction normal to the strike of the underlying (Conasauga) shale. High activity waste has been buried in auger holes at this disposal area.

Surface water drainage at SWDA 5 is predominantly southeast towards the Melton Branch (a small stream) and southwest towards White Oak Creek. The hydraulic gradient of subsurface waters trends to the southeast. The minimum depth to groundwater during the wet season at SWDA 5 ranges from 0 on the southern edge of the White Oak Creek floodplain to nearly 6 m (20 ft) near the summits of local hills. The water table in Melton Valley is a subdued replica of the surface topography.

SWDA 6 is located in Melton Valley immediately northwest of White Oak Lake, and immediately southwest of an intermittent stream that separates the disposal area from intermediate level liquid waste pits Nos. 2, 3, and 4. This disposal area is in current use and has been

since 1973. Approximately 28.3 ha (70 acres) have been set aside for disposal. This area can theoretically be divided into three sub-drainage systems for runoff. Two erosional depressions make this division. Surface drainage and groundwater movement is principally down-slope from the summits associated with each sub-basin towards intermittent streams (drainage gullies) and finally towards White Oak Lake. Between 25 and 35% of SWDA 6 may not be suitable for disposal because of steep terrain or a very shallow water table (less than 2 m below the surface). This groundwater table is also a subdued replica of the local topography and ranges from less than 2 m to over 6.5 m (6.6 to over 21 ft) near the summits of the local hills.

Nearly all of the waste trenches in SWDA 6 are located in areas where the highest groundwater level is below the base of the trenches. The notable exceptions are some small trenches excavated on a low terrace adjacent to White Oak Lake where water levels as shallow as 2.4 m (7.9 ft) below the surface have been observed during the seasonal rise in water table. Currently, the trenches are generally 5 to 6.5 m (16 to 21 ft) deep, about 3 m (10 ft) wide, and generally less than 16 m (52 ft) long. During the earlier days of operation, 2 trenches, whose length exceeded 32 m (105 ft), were excavated in the northern section of the disposal area. Trenches in this disposal area are generally excavated with lengths normal to the strike of the underlying shale formation, or at large angles to the strike in order to minimize slumping.

At the present time, non-TRU LLW is shipped from the laboratory facilities by truck to SWDA 6, and disposed of in trenches with a minimum backfill cover of 0.9 meters (3 ft). High activity radioactive waste with surface radiation levels exceeding 200 mR/hr is packaged in stainless steel drums, and transported to SWDA 6 in shielded casks for disposal in shafts.

Problems Encountered

Information on the disposal practices utilized at the first three disposal areas is comparatively scarce. However, the disposal practices utilized at the last three areas (SWDA 4, SWDA 5, and SWDA 6) and the difficulties experienced are well documented. These three disposal areas are discussed below.

Sometime after SWDA 4 was closed in 1959, a significant quantity of fill material was added on top of the disposal trenches. This fill increased the thickness of the site by approximately 0.6 to 6 m (2 to 20 ft), and resulted in a general rise in the groundwater table of this area. This groundwater table rise is attributable to the location of the site immediately adjacent to a large hill. The groundwater table elevation beneath this adjacent hillside was higher than the base of the emplaced waste. After fill emplacement, the groundwater table surface adjusted to the new contours resulting in saturation of the buried waste.

In addition, several surface seeps have been observed at SWDA 4.[2,4] These seeps are probably a result of semi-permanent perched water bodies within the trenches, which have probably resulted from infiltration of precipitation into the more permeable trench backfill and waste. The principal radiocontaminant released from SWDA 4 is ^{90}Sr; concentrations of this isotope in the seeping liquid are approximately 5×10^{-6} microcurie per milliliter (uCi/ml).[4] The calculated discharge of ^{90}Sr from the site in the mid-1970's was between 1 and 2 curies per year.

Some mitigative measures have been attempted at SWDA 4. In the early 1970's, suggestions for surface and groundwater diversion systems were made. The potential success and economics of installation of the groundwater diversion system (a drainage trench bordering the entire upgradient side of the disposal area) were questioned and this

construction was deferred. In 1976, however, interceptor and conductor drainage ditches were constructed as an improvement to the disposal area to prevent surface runoff from the northwest catchment area (upgrade of the disposal area). This system has been observed to effectively transport surface runoff from the disposal area ground surface. Yet, in the few years after construction of the drainage network, no significant decrease in ^{90}Sr discharges has been observed.[4]

Surface seepage of contaminated water has also been observed at SWDA 5. Thirteen different seeps have been identified along the southern ends of very long trenches trending perpendicular to the structural geologic strike of subsurface rocks.[4] These seeps have occured as a result of the "bathtub" effect and the use of very long trenches excavated lengthwise to the slope of the ground. The bathtub effect describes filling of a disposal trench with water which occurs when the rate of infiltration into the trench is much greater than the rate of percolation out of the trench over long time periods. After the trench fills with water, the height differential between the two ends of the trench provides a driving force for surface seepage.

The primary cause of the surface seepage was the construction of the trenches over significant topography in conjunction with waste instability (see below), and not the fact that the trenches were long. Contributing to this situation was the high annual precipitation (about 55 inches) experienced at the site coupled with subsidence of disposal trench covers resulting from degredation of compressible waste and production of internal trench voids. This latter effect has been observed in SWDA 5 and other disposal areas and promotes increased percolation of rainwater through a trench cap and into the trench.

From 1967 through 1977, the annual discharge of ^{90}Sr from SWDA 5 was slightly over 1 curie. High concentrations of ^{90}Sr and significant

concentration levels of ^{238}Pu and ^{244}Cu were observed in one of the SWDA 5 seeps.[5] A program was initiated in 1975 to significantly reduce the infiltration of water into and out of the disposal trenches. The first two projects included the installation of an impermeable barrier (a synthetic polyvinylchloride (PVC) membrane cover) in four of the trench covers, and the construction of two concrete dams (to reduce the hydraulic head between the ends of the trenches) in two of the trenches. The impermeable synthetic membrane was installed over an area of about 0.4 ha (one acre). To accomplish this installation, approximately 0.61 m (2 ft) of overburden was removed. After construction of the two concrete dams, the membrane was emplaced. The overburden material was then replaced, and the reworked area was reseeded with grass to reduce erosion.[5]

During 1977, a surface seal was installed over an area of approximately 0.18 ha (0.44 acres) which covered 14 small and moderately sized trenches. The surface seal consisted of a bentonite-shale mixture with bentonite applied at a spatial rate of about 0.04 kg/m^2 (0.008 lbs/ft^2). Since the installation of the PVC membrane and concrete trench dams, two years of streams monitoring has indicated a significantly reduced discharge rate of ^{90}Sr from SWDA 5.[5] The efficacy of the bentonite-shale seal in reducing discharges from the site has yet to be proven; however, reasonable hopes for success exist.

To date, no seepage or migration of radioactivity from the trenches has been observed at SWDA 6. However, contaminated trench leachate has been observed within individual disposal trenches. Strontium-90 concentrations in the trench leachate as high as 880 pCi/ml have been observed.[5] These trench leachates appear to date to have been confined to the disposal trenches.

Mitigative measures to prevent infiltration of water into SWDA 6 trenches have been performed in two areas covering approximately

0.33 and 0.69 hectares (0.82 and 1.70 acres), respectively. A bentonite-shale mixture was employed to prevent infiltration.[5] The efficiency of these mitigative measures cannot be stated at this time.

4.1.3 Discussion

In summary, the disposal areas at ORNL exhibit both positive and negative attributes with respect to disposal site performance. These positive and negative attributes include both natural factors and man-made impositions. The negative natural features of the sites include high precipitation rates, fractured subsurface media, shallow groundwater tables, and relatively limited acreage for optimal shallow land burial. The negative features of the sites are counteracted to varying extents by the positive natural site features of high adsorptive capacity, low soil permeability, and lack of significant erosional problems.

Man-made contributions to the sites have both benefited and detracted from disposal site performance. Negative impositions include disposal where the water table is exceedingly high, poor recordkeeping in the early days of operation, and alteration of the subsurface hydraulic regime. Significantly contributing to the surface seeps at SWDA 4 and 5 have been the compressible nature of the disposed waste, the construction of very long disposal trenches excavated lengthwise to the slope of the ground, and initial insufficient attention given to operational techniques (e.g., compaction, improved trench covers, site drainage, waste volume reduction) which would reduce the influx of water into the trenches.

The principal positive man-made contributes which have been employed to correct the negative impositions have included mitigative measures to impede infiltration into the disposal trenches, improved site selection techniques to avoid potentially problematic situations,

improved waste segregation methods, and employment of volume reduction techniques for compressible materials.

Significant improvements in methodology and operations of shallow land burial have been accomplished over the past 35 years. Although moderately significant discharges of radiocontaminants have been observed at ORNL in the past 10 years, DOE discharge limits at the laboratory have not been exceeded. The problems discussed above, however, have led to expensive maintenance and remedial programs at the disposal areas.

4.2 Los Alamos Scientific Laboratory (LASL)

The LASL site consists of approximately 11,200 ha (28,000 acres) in and adjacent to Los Alamos County, New Mexico. The laboratory has been operating since 1943. The work at LASL includes design and development of nuclear weapons; research programs in nuclear physics, chemistry, biology, biomedicine, radiochemistry, conventional explosives, metallium, hydrodynamics, and hydrogeology; inertial confinement systems for fusion energy; space physics; laser research; and geothermal power research.

4.2.1 Site Environmental Characteristics

LASL (and its associated shallow land burial sites) is located on the Pajarito Plateau in Los Alamos County, New Mexico.[7] The Pajarito Plateau, which flanks the eastern side of the volcanic Jemez Mountains, is 16-24 km (10-15 miles) wide and more than 48 km (30 miles) in length. This Plateau is bounded by the Sierra de los Valles on the west, the Rio Grande river valley on the east, the Puye Escarpment on the northeast, and by Canada de Cochiti on the southwest. The Pajarito Plateau lies at an elevation of 2377 m (1800 ft) above sea level on the west and slopes to an elevation of 1890 m (6200 ft) above sea level on the eastern side adjacent to the Rio Grande river

valley. The plateau has been incised to depths ranging from 60 to 122 m (197 to 400 ft) by numerous southeast trending intermittent streams. The eastern edge of the plateau rises 91 to 305 m (300 to 1000 ft) above the Rio Grande.

The Pajarito Plateau is underlain by several sedimentary and volcanic rocks ranging from Tertiary to Quaternary. These rocks are underlain by pre-Cambrian crystalline basement rocks. The specific formations underlying the Pajarito Plateau include the Bandelier Tuff, the basaltic rocks of Chino Mesa, the Puye conglomerate, and the Tesugue formation. The Bandelier Tuff includes a bedded pumice-fall deposit, a massive tuff-breccia of ash flow origin, and welded ash flows. The basaltic rocks of Chino Mesa are Pliocene to later Pleistocene lava flows which erupted from the Cerros del Rio (a source located east of the Rio Grande). These lava flows are 400 m (1300 ft) thick in some places.

The Puye conglomerate is a Quaternary sedimentary deposit consisting of pebbles, cobbles, and small boulders of quartzite, granite, and quartz with some volcanic debris mixed in a matrix of arkosic sand. The Tesugue formation is a middle Miocene to early Pliocene sedimentary rock containing two minor volcanic units. The formation primarily consists of soft arkosic sandstone and minor conglomerate.

The geology and structure of the LASL vicinity is strongly related to volcanic activity initiated about 12 million years ago (late Miocene) and culminating about one million years ago (Mid-Pleistocene) by two gigantic pyroclastic outbursts (similar to, but larger than, the 1980 eruptions occurring at Mt. St. Helens, Washington). These two gigantic outbursts left the Bandelier Tuff as remnants of these events. Each of these outbursts deposited nearly 209 km^3 (50 mi^3) of rhyolite ash and pumice, mainly as ash flows. Each explosion created a caldera (large crater). The LASL site exists within the Jemez Mountains which are located along the western border of the Rio

Grande Rift (a linear structure and depression formed by faulting about 20 million years ago). The Jemez volcanic rocks are faulted by numerous north-trending faults.

The meteorologic conditions at LASL are generally conducive to waste disposal. The amount of rainfall and melted snow water that can potentially come in contact with disposed waste is quite low. The climate at LASL is semi-arid, continental mountain. The average annual precipitation at LASL is about 465 mm (18 in). Approximately 75% of this precipitation occurs between May and October (the warmer months). The greatest observed shower activity occurs in August when approximately 3 mm (.11 in) of rain or more can be expected 1 out of every 4 days. During winter snow, accumulations averaging 1000 mm (40 in) can be expected. The relative humidity at the site is quite low; the mean annual humidity value is 41%. During spring when humidity drops to its lowest values, the average humidity is 30%. During summer, when humidity rises to its highest, the average humidity is about 50%. The prevailing winds at LASL are from the south and are generally (roughly 80% of the time) less than 16 km/hr (10 mph). The highest recorded temperature at the site is 35°C (95°F) with 32°C (90°F) as a typical maximum temperature (recorded about 2 days per year). The highest temperatures are generally recorded in July. Sub-freezing temperatures have been recorded in all months except July and August. Only 18 days are recorded to have sub-freezing temperatures during an average winter. These extremes are not detremental to the successful performance of a disposal site.

The groundwater at LASL occurs either in the form of perched water (perched saturated zones) or within the main subsurface aquifer. The main aquifer occurs within the Tesuque Formation of the Sante Fe Group at depths ranging from 200 m (660 ft) along the eastern margin of the Pajarito Plateau to 400 m (1300 ft) along the western margin. The aquifer is recharged through the intermontane (intermountain) basins formed by the Valley's caldera and the eastern margin of the

Sierra de Los Valles. Groundwater velocities from the recharge area to the Rio Grande subsurface drainage area are approximately 30 cm (12 in) per day. Some of the subsurface water discharges through seeps and springs along the Rio Grande. The Tesuque Formation (the aquifer) generally consists of beds of siltstone and sandstone with some lenses of conglomerate and clay. Perched saturated zones occur within the interbedded basalts of the Puye Formation near the eastern margin of the plateau and in several canyons near the laboratory property. Perched water is also present in small bodies within the recent alluvium of Mortandad and Pajarito Canyons. It is believed that many of these perched saturated zones are seasonal occurrences.

With respect to surface water, the Rio Grande is the only perennial stream within the general vicinity of LASL. Within the upper reaches of Guaje and Los Alamos Canyons (which cut the Pajarito Plateau) some natural perennial flow occurs. The existing perennial flow is depleted by infiltration and evaporation as it cuts across the plateau. Treated sewage effluent comprises the bulk of the perennial flow in the upper and middle reaches of Sandia and Pueblo Canyons. Intermittent flow resulting from releases of treated industrial effluents can be observed in several of the other canyons on the plateau.

The adsorptive capacity of the LASL soils used for LLW disposal is quite good. The measured cation exchange capacity of the Bandelier Tuff is 0.5 to 3.0 milliequivalents per hundred grams of sample (meq/100g). The expected distribution coefficient for cesium in the locally derived soils in the Bandelier Tuff would be 100-150 mg/l.

4.2.2 Disposal Experience

Background

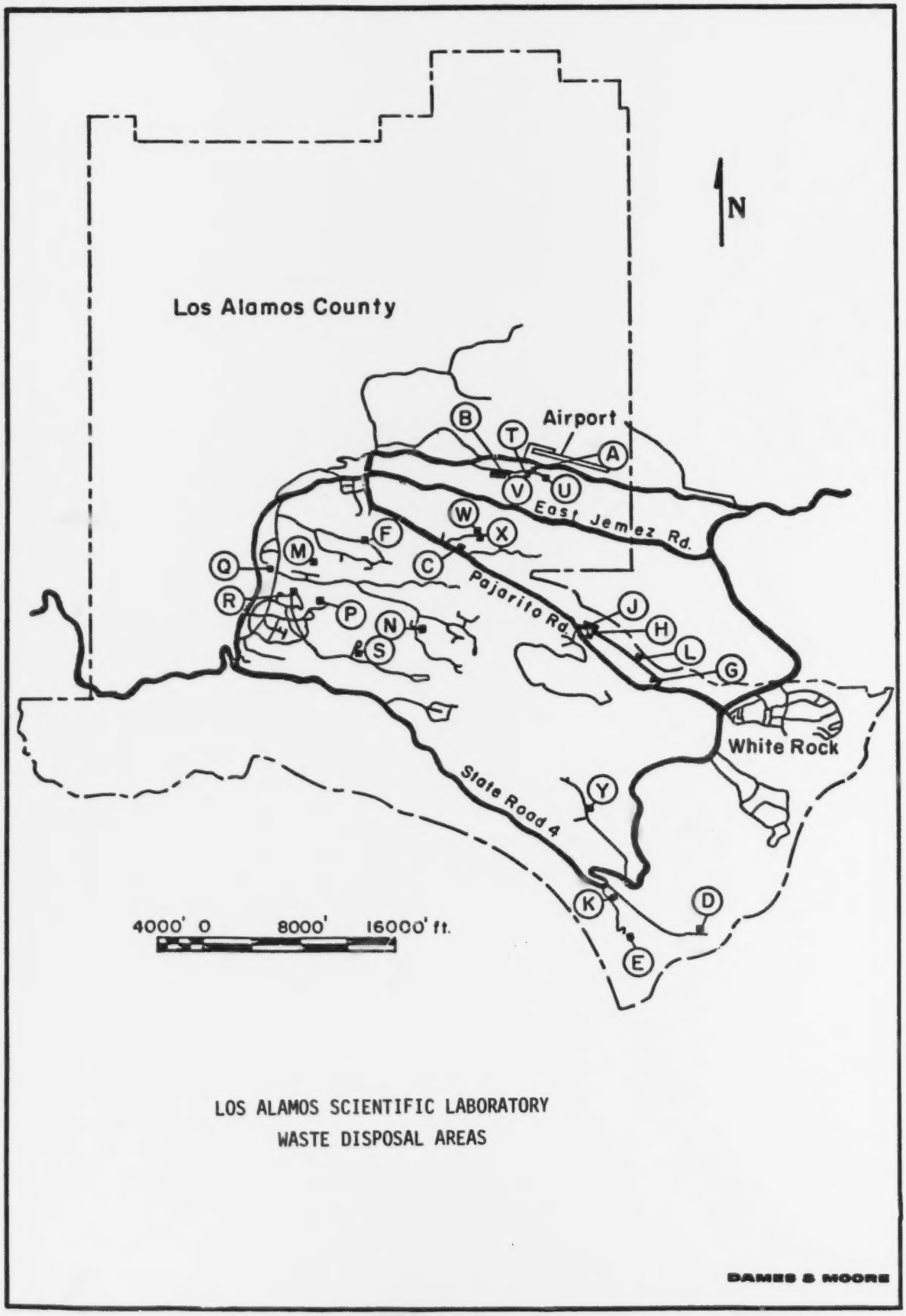
The radioactive solid wastes generated at LASL are categorized as either routine or non-routine. Routine waste consists primarily of

laboratory trash (mostly combustible), chemicals, oil, animal tissue, small equipment, chemical treatment sludge, cement paste, classified materials, and hot-cell waste. Non-routine waste generally consists of building debris, large contaminated equipment, and contaminated soil or rock. These non-routine wastes are usually generated during site cleanup, facility renovation, or facility decommissioning projects.[6,7]

Numerous areas for shallow land burial have been employed for waste disposal at LASL since 1944 (Figure 4-2). Detailed information on history and environmental setting is currently available for only eight of these areas.[6,7] Three areas are presently in use (areas A, G, and T; Area T is a liquid waste disposal site).

Disposal Area A is in the northern section of LASL and has been used intermittently since late 1944. During the early periods (1944-1947), two disposal trenches and two liquid waste storage tanks were employed for waste disposal. In the later periods (1969-1976), a large trench was used for solid waste disposal. The waste buried in the trenches is principally thought to be alpha contaminated waste with some small amounts of beta-gamma waste. The alpha contaminated material probably included uranium, plutonium, and polonium. The estimated volume of radioactive waste in the trenches is about 1020 m^3 (36,016 ft^3).

Disposal Area B is located about 600 m (2000 ft) west of Disposal Area A, adjacent to DP Road (Route 4) at LASL. Records of waste disposal in Area B for the years 1944 to 1947 are incomplete; however, the waste disposal method probably entailed a series of trenches similar in dimension to those in Area A. The radioactive waste was emplaced in Area B trenches by a three worker team (aided by the waste truck). A ramp was used to direct the waste into the trench, and a bulldozer used to cover the trench with backfill once a week. The majority (90%) of the waste disposed in Area B is believed to be trash, mostly consisting of rags, paper, rubber gloves, small metal apparatus, and



LOS ALAMOS SCIENTIFIC LABORATORY
WASTE DISPOSAL AREAS

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FIGURE 4-?

glassware. The remaining waste volume is thought to consist of ventilation ducts and large metallic apparatus. The principal radiocontaminants buried in Area B are plutonium, uranium, polonium, americium, actinium, and lanthanum. About 21,400 m^3 (756,000 ft^3) of solid radioactive waste were disposed within Area B.

Disposal activities at LASL were eventually discontinued at Area B and relocated. This action was taken due to the expansion of the LASL facilities and the surrounding community and to the desire, for health and safety (and nuisance) considerations, to carry out waste disposal activities at locations farther removed from living and working areas at the site. Contributing to this decision was a fire that broke out in Area B in the Spring of 1948 which burned for several hours. In 1966, the western two-thirds of Area B was covered by a layer of asphalt and is currently leased by Los Alamos County for storage of privately-owned boats and trailers.

Disposal Area C is located on the plateau between Los Alamos and Pajarito Canyon along Pajarito Road. This disposal area was used for radioactive waste disposal between 1948 and 1974. Waste was disposed of in 7 trenches, one of which was reserved exclusively for the disposal of non-radioactive hazardous wastes, and in 108 disposal shafts. This was the first disposal area which maintained detailed records for its entire length of operation. Four of the seven waste trenches had dimensions of about 186 m (610 ft) long and 12 m (40 ft) wide. The remaining trenches ranged from 55 to 214 m (180 to 705 ft) long, 7.6 to 33.5 m (25 to 110 ft) wide, and 3.7 to 5.5 m (12 to 18 ft) deep. All excavations at this site (and Areas A and B), were cut into the Tschirege Member of the Bandelier Tuff. The waste buried in the trenches at Area C contained (decay corrected to 1973) 25 curies (Ci) of uranium isotopes (234, 235, 236, and 238), 26 Ci of ^{239}Pu, and 149 Ci of ^{241}Am. The waste disposed in the trenches included contaminated trash in boxes, bags, and drums; and sludge in drums from one of the LASL treatment plants.

The shafts dug at Area C typically were less than 1 m (3.3 ft) in diameter and between 3 and 7.6 m (10 and 25 ft) in depth. The 108 shafts at Area C contain nearly 49,400 Ci of mostly short-lived activity, including about 49,000 Ci of H^3, 40 Ci of ^{22}Na, 20 Ci of ^{60}Co, 31 Ci of $^{90}Sr/^{90}Y$, 5 Ci of ^{233}U, 1 Ci of ^{226}Ra, <0.1 Ci of other uranium isotopes, 50 Ci of fission products, and 200 Ci of activation products. Information as to specific waste volumes is not available.

Non-routine waste disposed at Area C includes debris from building demolition, non-routine classified materials, and chemical waste.

Although Area D is labelled as a disposal area, it is not truly a shallow land burial site. Area D consists primarily of two underground chambers used for test detonations of TNT, polonium, uranium, and cobalt. Since a majority of the radioactivity was from ^{210}Po (half-life - 138 days), it is unlikely that any significant contamination remains.

Disposal Area E is located off of State Road 4 (Route 4) near the southeastern border of the laboratory. This disposal area contains one underground detonation chamber and six trenches, and was probably used between 1949 and 1962. This disposal area contains several hundred kilograms of ^{238}U.

It is doubtful that Area F represents a true radioactive waste disposal site. This site was probably opened in 1946 for the disposal of classified obsolete equipment, materials, and forms. Specific information on trench construction, waste types, and disposed radionuclides buried (if any) is not available.

Disposal Area G is the largest disposal area at LASL and has been used for waste disposal since 1957. Area G is located on Mesita del Buey between Los Alamos and Pajarito Canyons on the Pajarito Plateau

adjacent to Pajarito Road. This site was selected because of its relative isolation and its suitable acreage for waste disposal. This area includes 18 trenches and 81 shafts (as of 1977). Recordkeeping for the entire history of disposal Area G has been good.

Many types of wastes in various containers have been disposed in the trenches and shafts at Area G. Typical wastes disposed into trenches included contaminated trash from laboratories, failed equipment, and solid residues from liquid waste treatment (e.g., sludges and concentrates). The disposal trenches typically range in size from 120 to 180 m (400 to 600 ft) in length, 8 to 30 m (26 to 98 ft) in width, and 8 to 11 m (26 to 36 ft) in depth. In addition, there are specific site (LASL) guidelines which require minimum spacing between the trenches and between the canyon edges.

Waste disposed at Area G is emplaced in layers within the trenches. The disposal trenches are filled with waste to within 1 m (3.3 ft) of the ground surface, and are then backfilled to the original ground level. The trench covers are often mounded to 1 m (3.3 ft) or greater above the original ground surface.

At Disposal Area T, liquid wastes were disposed of in adsorption bed trenches up until 1968. Currently, various wastes including sludges, slurries, and concentrates are mixed with cement and pumped down auger shafts (cement paste). Additionally, high beta-gamma waste, tritium waste, animal tissue, and classified contaminated waste are placed into deep shafts augered into the volcanic (Bandelier) tuff. These shafts are generally augered to a depth of between 7.5 and 20 m (25 and 66 ft) with 0.6 to 2.4 m (2 to 8 ft) diameters. These auger shafts are generally filled to within 1 m (3.3 ft) of the ground surface, or are backfilled to achieve a radiation level below 100 mR/hr at the surface. A total fissile material limit of less than 500 g per shaft is imposed. When each shaft is filled, the annular space (void spaces between waste packages) is then filled with

excavated tuff debris (silt, sand, and gravel sized backfill). Finally, each waste shaft is plugged with a concrete plug having a minimum thickness of 1 m (3.3 ft). Concrete is mounded at the ground surface to provide a good seal and provide drainage away from the shaft.

The radioactive waste generated at LASL is packaged to provide safe transport and handling from the generation point to the operating disposal area. With the exception of the packaging for tritium waste, no credit is given to package integrity after burial. Most low-activity trash waste is compacted and baled at Disposal Area G before burial. Alpha, beta-gamma and tritium air monitors are operated continuously within the compactor-baler facility. Overall volume reductions of between 20 and 25% have been achieved for all waste at LASL. The volume reduction factors achieved for trash alone are considerably higher. Thorough waste assay and segregation methods are in practice at the LASL disposal areas. All personnel, equipment, and vehicles involved in the disposal operations are monitored before leaving the areas. Surface runoff at the disposal areas is controlled by the construction, use, and maintenance of drainage ditches.

Problems Encountered

Available information on radioactive waste disposal at LASL[6,7] has indicated relatively few recorded waste management problems. Like other DOE facilities opened and originally operating under a war-time atmosphere, early records of waste disposal are often incomplete. Some waste disposal areas were not adequately identified, fenced, and posted. In the past, the locations of some individual disposal trenches, pits, and shafts were not adequately documented, nor was the waste volumes and radionuclide quantities and concentrations adequately recorded. Environmental monitoring of disposal areas was occasionally overlooked. In other cases, surface water runoff was not always adequately controlled and there have been incidents when

precipitation runoff was allowed to flow into open disposal trenches and pits.

Incidents have also occured which involved temporary contamination of site grounds as well as temporary release of airborne contamination. These incidents of temporary surface contamination, however, do not appear to have been as extensive as at some of the other sites. On one occasion, for example, liquids waste disposed into seepage pits in Area T overflowed the pits and contaminated some ground surfaces.

As discussed above, liquid waste is no longer disposed directly into open pits but combined with cement to form a paste prior to disposal into deep shafts. There have also been a number of recorded incidents of temporary disposal trench fires. Apparently greatly contributing to these fires were: (1) the practice of disposing uncontaminated hazardous chemicals co-mingled with radioactive waste, and (2) infrequent covering of emplaced waste with soil. The former factor also reduced disposal efficiency by otherwise occupying valuable disposal space As a result, site operations were changed to provide for segregated disposal of non-radioactive waste from radioactive waste, and more frequent and complete covering of emplaced waste.

4.2.3 Discussion

In summary, it can be seen that the LASL disposal areas exhibit both positive and negative attributes with respect to disposal site performance. The positive natural factors at LASL include low precipitation rates, high adsorptive capacity of the disposal media, relatively low permeability of the disposal media, lack of significant erosional problems, and a deep groundwater table. There appears to be no significant negative natural factors at the LASL disposal areas with the possible exception of the relative proximity of some of the disposal areas to canyon edges (raising the possibility of potential long-term erosional problems).

In addition to these natural factors, several man-made impositions have both benefited and detracted from the performance of the LASL disposal areas. The negative contributions are limited and have been discussed above. The principal positive contributions have included a large volume reduction effort for compressible wastes (which helps to reduce trench subsidence), improved operational procedures including improved fire control, discontinuing of liquid disposal in pits (new liquid wastes are combined with cement), and improved waste segregation and assay methods. Another positive factor has been the demonstrated reuse of a disposal area (Area B) for useful purposes -- in this case a parking lot. There has been no significant release of radiocontaminants from the solid waste disposal trenches at LASL. In general, the performance of the disposal pits, trenches, and shafts at LASL has been good.

4.3 Hanford Reservation (HR)

The HR is located in the Pasco basin, a semi-arid region in the southeastern part of the state of Washington. The site occupies 148,000 ha (365,000 acres). The site was opened in 1943 as part of the Manhattan Project to construct and operate nuclear reactors and chemical separation facilities for the production and purification of plutonium for possible use in nuclear weapons. A total of nine reactors were built along the Columbia River. These include eight graphite-moderated reactors which used Columbia River water for once-through cooling, and one dual purpose reactor (production of both plutonium and steam for generation of electricity) with recirculating coolant water.

At the present time only the dual purpose reactor (N Reactor) remains in full service. In addition to these reactors, numerous chemical processing plants, laboratories, and supporting facilities were constructed on the reservation.[8]

4.3.1 Site Environmental Characteristics

The location of the reservation is within the Columbia Basin geologic province.[8] The Columbia Basin is underlain by great thicknesses of flood lavas of the Columbia River Basalt Group. These lava flows and the ground surface of this portion of the state of Washington dip radially inward toward the Pasco Basin (the off-centered physiographic low of the larger Columbia Basin). The Pasco basin was apparently formed by slow and prolonged subsidence concomitant with the filling of this basin with basaltic lavas. The beginning of the uplift of the northern Cascade Range and the production of the basins (like the Pasco) probably occurred some 15 million years ago.

The HR is situated within the Pasco Basin on the partly dissected and modified alluvial plain of the Columbia River. Surface elevations range from 105 to 245 meters (345 to 800 ft) above mean sea level.[2] This alluvial plain generally contains a mixture of aggradational and degradational stream features that reflect the history and development of the Pasco Basin during the late Pleistocene and the entire Holocene epoch (covering the last 100,000 years of geologic history). As a result of stream channel shifting, downcutting, and flooding over this period of time, two benches or terraces were formed (one terrace at about 160 m (525 ft) elevation and the other at about 130 m (427 ft) elevation. Following the river course shift, two sets of dunes were formed. These dune features are relatively dominant site features.

The soils in the alluvial plain are typically coarse grained. The Ringold Formation, which is overlain by glaciofluvial deposits from its ancestral Columbia River, lies above the Yakima Basalt (the thick member of the Columbia River Basalt Group.) The Ringold Formation, with the exception of some gravel and conglomerate layers, generally consists of sand, silt, and clayey silt in varying proportions. The glaciofluvial deposits generally consist of sand and gravel, with some intermixing of silt. The cation exchange capacity of these segments

ranges from 4.0 to 27.2 meg/100g for the unsaturated zone sediments (upper Ringold Formation and glaciofluvial deposits) and 4.0 to 9.3 meg/100g for the saturated zone materials (Ringold Formation).

Eolian sediments consisting of very fine sands and silts are found throughout the reservation. Some of the dunes have stabilized, and Mount Mazama ash beds (from Crater Lake, Oregon) have been incorporated into these dunes. This indicates that the period of formation for some dunes occurred some 6000 to 7000 years ago. At several locations within and around the reservation the vegetative cover on the dunes has been destroyed by road cuts and brush fires, some active dune migration has resulted.

The meteorological conditions at the HR are of great import to the waste disposal operations. Air temperature in winter generally ranges from -6 to 3°C (21 to 37°F), summer temperatures generally range from 16 to 33°C (61 to 92°F). The average annual precipitation at the reservation is about 160 mm (6.3 in). The annual evapotranspiration at the site is approximately 180 mm. About 45% of the precipitation in winter is in the form of snow. Winds at the site are predominantly from the north-northwest and northwest at wind speeds ranging from 7.4 to 22.2 km/hr (4 to 12 knots). According to the frequency distribution of wind speed and wind direction data collected over a recent 15 year period (1955-1970), the annual wind speed distribution for the 0-3 knot, 4-7 knot, 8-12 knot, 13-18 knot, 19-24 knot, and over 24 knot speed classes are 5.09%, 10.84%, 6.31%, 4.07%, 2.13%, and 1.57%, respectively. The relatively dry conditions, noncohesive soils, and moderate wind speeds result in moderately significant transport of sediments across the reservation. This combination of factors results in relatively high long-term instability of soils in the disposal areas.

The depth to the saturated zone (an unconfined aquifer) ranges from less than 16 meters (about 50 ft) near the Columbia River (within the

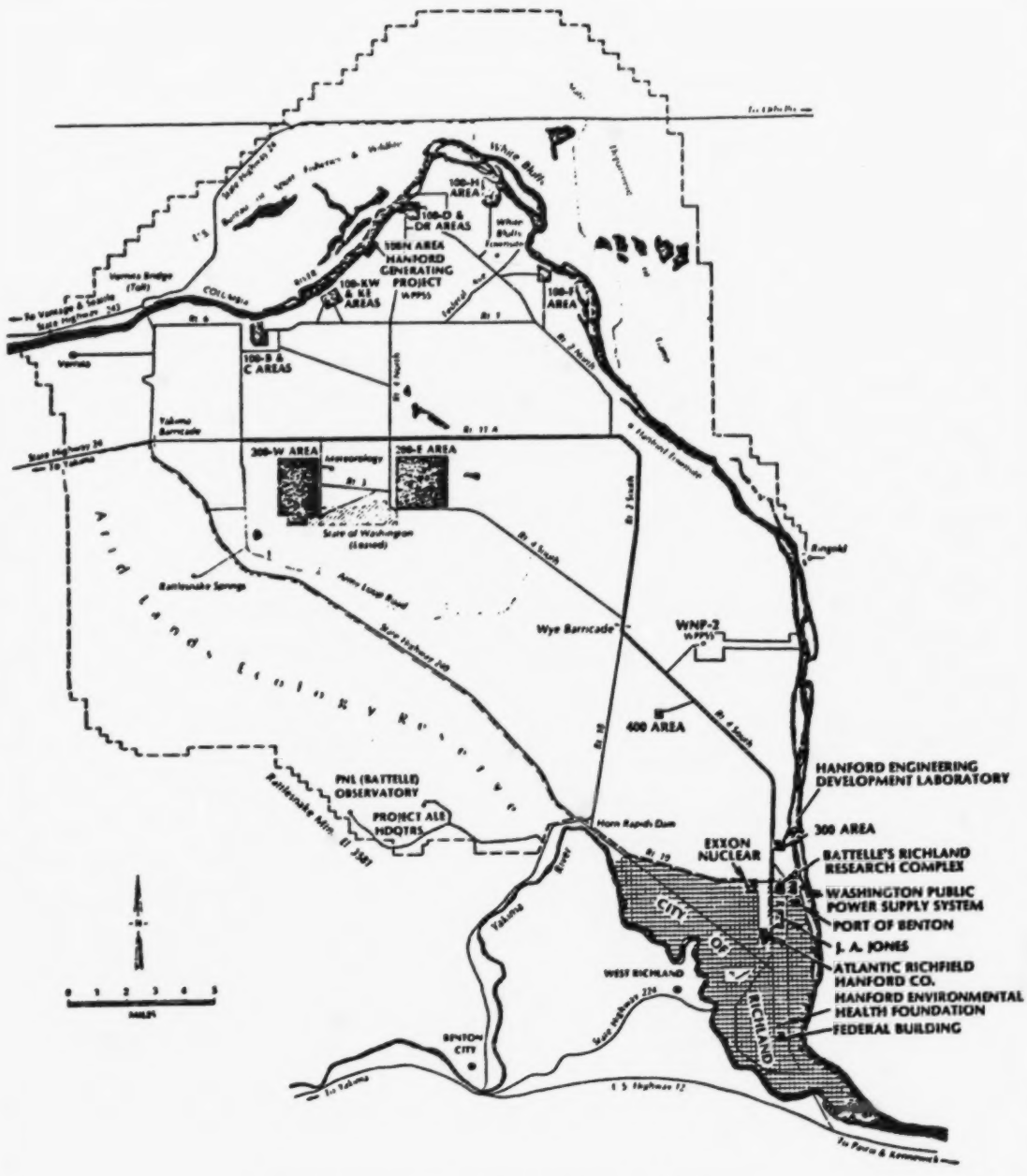
100-Area) to over 90 m (300 ft) several miles from the river. The unconfined aquifer beneath the site ranges in thickness from about 15 to 75 meters (50 to 250 ft). The bottom of this aquifer usually consists of the lowest layer of the Ringold Formation (typically a clayey silt horizon). The horizontal hydraulic conductivity of the aquifer is reported to range from 0 to 61 m/day (0 to 200 ft/day) with a normal range of 4.5 to 24 m/day (15 to 80 ft/day). The horizontal hydraulic conductivity of the glaciofluvial deposis ranges from 365 to 4270 m/day (1200 to 14,000 ft/day). Consumptive use of the aquifer underneath the reservation includes withdrawal of about 7.4 liters per second (lps) (0.26 cfs) from several wells on the reservation. Twenty wells in the city of Richland, Washington provide water which has been withdrawn from the aquifer.

Liquid discharge into cribs and pits from processing plants on the reservation provides the principal means of locally recharging the aquifer. The average rate of recharge from liquid disposal for the period 1944 to 1972 was 552 lps (19.5 cfs). The highest rates of recharge have occurred in the 200-Areas where liquid has been disposed of at a rate of 127 to 225 lps (4.5 to 8.0 cfs). These high recharge rates have resulted in groundwater "mounds" (elevated piezometric surfaces). The water table elevation sometimes rises to 18 to 21 m (60 to 70 ft) above the natural water table.

4.3.2 Disposal Experience

Background

Radioactive waste generation at the HR occurs at several separate complexes within the site (Figure 4-3). Research, development, and production work at HR is performed by several DOE contractors. The principal contractors at HR are the Rockwell Hanford Company, Battelle Memorial Institute (Pacific Northwest Laboratories), and United Nuclear Industries. Work activities at HR are performed within



HANFORD RESERVATION

SOURCE: REF. 8

DAMES & MOORE

FIGURE 4-3

several facility complexes. These complexes include the (a) 100 Areas where nuclear reactors produce plutonium, (b) 200 Areas where fuel and plutonium processing and high and LLW management occurs, (c) 300 Areas where fuel fabrication facilities and laboratory complexes are located, (d) 400 Areas containing the Fast Flux Test Facility, and (e) 600 Area which denotes all of reservation not included in the above designated areas.[6,8]

Waste generated at the HR has included high and low level liquids as well as solid wastes. Since the beginning of Hanford operations, high level liquid waste generated from fuel reprocessing operations has been stored in large storage tanks in a number of locations in the 200 Areas. A program has been ongoing for several years to remove the Cs-137 and Sr-90 activity from the waste liquids and to reduce the liquids to a salt cake. This is accomplished by evaporation and crystallation and solids accumulation in existing storage tanks.

Low level waste liquids have been disposed through use of several ponds and cribs located at various locations in the Reservation, particularly in the 200 Areas. (A crib is constructed by digging a ditch about 20 feet deep and up to 1400 feet long, backfilling with rock, and then covering with an impermeable membrane and soil. A pipe running the length of the crib is perforated to allow even distribution along the crib length.) Liquids released into the ponds and cribs are allowed to slowly percolate through the soil and eventually into the groundwater. The liquids are mostly process and steam condensates which have a potential for containing radioactivity due to process upset or equipment failure. For most isotopes, ion exchange with the underlying soil provides considerable hold-up prior to reaching the underlying aquifer. A total of 177 cribs have been constructed in the 200 Areas although the use of cribs to dispose of radioactive liquids has decreased.

Radioactive solid wastes generated at the HR have been stored and

disposed of by several variations of shallow land burial. At least 65 sites within the reservation have been used for solid waste storage or disposal. In early days of operation, disposal sites were generally located in reasonably close proximity to the facilities generating the waste. Currently, however, only the 200 Areas are used for waste disposal.

Disposal pits and trenches at HR are typically 1.5 to 5 m (5 to 16 ft) wide, 4 to 8 m (13 to 26 ft) deep, and variable in length (Ref. 7). Disposal shafts are typically 2.4 m (7.9 ft) in diameter and 7.4 m (24 ft) deep. Through the end of fiscal year 1977, a total of 187,600 m^3 of fission product waste and 607,000 kg of uranium had been disposed of at Hanford. This volume of waste contained over 2,000 Ci of activity.

A total of 26 LLW disposal sites have been employed at the 100 Areas section of the reservation between the years 1944 and 1974. These waste disposal sites occupy approximately 26 hectares (64 acres) of land. Two disposal sites were used between 1954 and 1960 for the disposal of contaminated materials resulting from reconstruction and repair construction work. One of the disposal sites was employed between 1956 and 1968 for the disposal of fuel spacers. Some disposal sites were employed only to handle special wastes generated from specific short term projects (e.g., disposal area 118-B-5). Several disposal sites within the 100 Areas were used between 1946 and 1968 for the disposal of liquid waste.

Within the 200 Areas, a total of 28 sites have been employed for waste disposal or storage between 1944 and and the present. A majority of these sites are now inactive. In the 200 East Area, a total of 15 sites have been employed. These include three dry waste disposal sites, four industrial waste disposal sites, two regulated equipment storage sites, two construction waste disposal sites, one vault, one site for disposal of contaminated concrete, and two tunnels. Storage

and disposal sites in the 200 West Area include eight dry waste disposal sites, two industrial waste disposal sites, two vaults, and one regulated equipment storage site. Filled disposal trenches in the 200 Areas are normally closed by backfilling with at least least 2.4 m (8 ft) of soil and are then covered with a layer of cobbles to preclude problems with wind erosion. High activity non-TRU waste is typically disposed in caissons similar to those used for storage of high activity TRU waste.

Asphalt pads are currently employed for retrievable storage of TRU wastes at Hanford. Drums and boxes containing low-activity waste (low surface radiation levels) are stacked on the pads and flame retardent plywood is emplaced between and on top of each stack of boxes or drums. Each completed stack is covered with a polymer membrane and backfilled with 1.3 m (over 4 ft) of overburden. The ratio of stored TRU waste volume to utilized land area is approximately 6.6 x 10^5 m^3/m^2. In 1972 and 1973 TRU waste was stored in a concrete "vee" (v-shaped) trench. Waste barrels were placed into the concrete lined trench at a 45° angle. The completed stack in the "vee" trench was then covered with a steel cover, and backfilled with 1.2 m (about 4 ft) of soil. This storage method was replaced by the current method to reduce storage costs. High-activity TRU waste is stored in underground caissons. The caissons employed are made of reinforced concrete and are buried 4 m (13 ft) below the ground surface. The TRU caissons are fitted with 0.9 m (3 ft) diameter convoluted chutes to reduce external radiation levels.

The two tunnels at HR contain railroad spurs and are used to store very large, heavy, or highly contaminated equipment on railroad flat cars. The contamination associated with materials stored in these two tunnels is usually activation products; however, other TRU and non-TRU materials are present. One of these tunnels contains 8 filled flat cars and is now inactive. The second tunnel is 515 m (1690 ft) long and has a holding capacity of 42 flat cars with signficant storage space left.

Some TRU waste generated at Hanford is unsuitable for caisson or pad storage because of its size, security requirements, or surface radiation level. This waste is specially packaged and placed in a trench. When a special trench is filled, a plywood cover and a polymer membrane (PVC laminated nylon) is added before it is backfilled with 1.2 m (4 ft) of soil. All classified waste is covered on the same day that it is emplaced in a trench.

Within the 300 and 600 Areas at HR, 11 sites have been used for storage or disposal of radioactive waste. These disposal and storage sites contain miscellaneous solid radioactive waste which include uranium, plutonium, and fission products. These wastes have been buried in trenches and caissons.

Problems Encountered

Since the Hanford Reservation was opened, there have been a number of incidents involving low level waste management operations.(8) Two incidents (in 1954 and 1955) involved fires in waste disposal trenches in the 300 Area. An earlier fire (1951) involved a contaminated waste storage area. There have also been a number of incidents involving contamination of ground surfaces due to leaks or spills of of both high level and low level radioactive waste liquids due to incidents such as pipe breaks. A number of contaminated areas still remain on the reservation, although off-site impacts from the contaminated soils are believed to be minimal.

Other incidents recorded at Hanford have involved intrusion of plants and animals into disposed waste. For example, burrowing animals have, on occasion, burrowed into liquid waste disposal cribs in an effort to obtain salts deposited by the percolating liquids. Radioactive salts thus consumed were then dispersed by the burrowing animals and the predators.(9) On other occasions at the Hanford Reservation, swallows have been known to obtain radioactive mud from settling basins for

use in constructing nests.[9] Other incidents have been observed at the Hanford Reservation in which plants growing over disposal trenches and cribs have accumulated fission products and transuranic elements in shoot tissues.[10]

These plant and animal intrusion events have not resulted in significant impacts. However, solid waste disposal operations were altered so that a minimum of 8 ft of soil separates the top of the waste and the ground surface. A layer of cobbles was also added to deter burrowing animals (and to minimize wind erosion of the disposal trench covers). Studies have also been performed at the Reservation to investigate other potential barriers to biological intrusion.[10,11]

4.3.3 Discussion

The Hanford Reservation was opened during World War II, and expediancies which took place during early disposal operations reflected the pressures of the time period, and of the Cold War which immediately followed. These expediancies included poor recordkeeping and problems with management of contaminated liquids. In addition, more recent calculations by DOE have indicated that under conditions of a probable maximum flood, disposal sites located in the 100 and 300 Areas could be temporarily inundated.[8]

Over the years, however, a number of imprevements in site operations have been observed. These improvements have included significantly improved recordkeeping, utilization of thicker trench covers, improved volume reduction for compressible wastes, segregation of radioactive from non-radioactive wastes, an extensive environmental monitoring program, and a research program on waste/biosphere interaction. In addition, the use of cribs and ponds to dispose of radioactive waste liquids has been considerably reduced. All current disposal operations take place the the 200 Areas, which is well above the maximum level of the probable maximum flood.

In general, the natural site characteristics at HR appear to be suitable for good disposal site performance. Negative natural factors at the site include a high potential for wind erosion of site soils and relataively high unsaturated zone permeabilities. However current disposal practices incorporating thicker, stabilized trench covers should greatly mitigate and possibly eliminate this concern. The high unsaturated zone permeabilities are offset by the low annual precipitation rates, the high evapotranspiration rates, relatively homogeneous disposal media having high adsorptive capacities, and (in the 200 Areas especially) the relatively long distance to the saturated zone. Other positive factors include the ready availability of relatively flat-lying land suitable for waste disposal.

4.4 Idaho National Engineering Laboratory (INEL)

The INEL (formerly known as the National Reactor Testing Station) was created in 1949 by the Atomic Energy Commission (AEC) as a site where a wide range of nuclear research activities could be accomplished. A total of 51 research reactors and critical facilities (of which 17 are still operable) have been constructed at INEL. The research performed includes naval propulsion (including submarines), aircraft propulsion, light water reactor safety tests fast breeder reactor development, portable military power development, and other related research projects. The INEL site is also the home of the Idaho Chemical Processing Plant (ICPP) where spent fuel from government reactors is processed and improved fuel reprocessing techniques are developed. Disposal of various forms of solid LLW is carried out at the Radioactive Waste Management Complex (RWMC).

4.4.1 Site Environmental Characteristics

The INEL complex resides on 231,407 hectares (571,800 acres) of land

on the Snake River Plain.[12-18] The Snake River Plain is covered with sagebrush and was used sparingly by trappers and cattle-herders prior to the establishment of INEL. Several irrigation projects were initiated on the Snake River Plain in the early part of the twentieth century. The Snake River Plain cuts an opening 80 to 160 Km wide (50 to 100 miles) through the Rocky Mountains in the State of Idaho, and has an average elevation of 1493 meters (4,900 feet) in the vicinity of INEL.

The adjacent mountains rise to elevations exceeding 3650 m (12,000 ft). These bordering mountain ranges generally consist of Paleozoic and Mesozoic rocks which have been folded, faulted and uplifted during periods of Basin and Range tectonism. A narrow strip of green vegetation adjacent to the Snake River creates a striking contrast to the sparse sagebrush which dominates most of the Snake River Plain. The INEL area is underlain by a succession of Pliocene, Pleistocene, and recent balsatic lava flows. These basaltic flows have been extruded from rifts and volcanoes whose locations are rift controlled. The lava flows form layers of hard rock ranging in thickness from 3.1 to 30.5 m (10 to 100 ft). Both the physical characteristics and horizontal distribution of rock and sediment material vary considerably with the unconsolidated sediments, cinders and breccia interbedded with the basalt. The basalt flows of the Snake River Plain range from 1500 years to 7 million years in age. The majority of the interbedded sediments observed in the subsurface basalt are fluvial, lacustrine, or eolian in origin. Some interbedding with cinders and volcanic breccias has been observed in the Snake River Plain.

Theories on the origin of the Snake River Plain vary. Suggestions have included creation from a single downfaulted graben, a gigantic crustal downwarp, or a tensional rift (crustal thinning). Although the origin of the Snake River Plain is structurally complex, the structural geology of the area immediately surrounding INEL is not. The basalts underlying INEL show no significant regional dip, although

some of the sedimentary interbeds dip between 3.8 m/km and 4.7 m/km (20 to 25 ft/mile). The dip of these sedimentary layers is probably attributable to the manner in which sediments were deposited.

The climate at INEL has a strong influence on both the nature and quantity of surface water as well as on subsurface waters. The average annual precipitation at INEL is approximately 216 mm (8.5 in). The maximum amounts of rainfall occur in May and June, the minimum amounts are recorded in July. In 22 recorded years (1954 to 1976), only thirteen occurrences of rainfall greater than 25.4 mm (1 in) have occurred in any 24 hour period. In winter, the average maximum temperature is -2.7°C (27°F); the average minimum temperature is -16°C (3°F). In summer the average maximum and minimum temperatures are 30.5°C (87°F) and 10°C (50°F), respectively. Temperature extremes recorded over a 22 year observance period (1954 to 1976) include a low of -4.6°C (23°F) and a high of 39.4°C (103°F). The wind at the site is predominantly from the west and southwest. The recorded average wind speeds indicate a minimum speed of 8 km/hr (5 mph) and a maximum speed of 14.4 kilometers per hour (9 mph). The annual evaporation rate is approximately 914 mm (36 in). Data indicates an annual evapotranspiration for Idaho Falls of 502 mm (20 in).

The Snake River Plain aquifer underlies INEL; it consists of basalt flows and interbedded sediment. This unconfined aquifer has a water table depth ranging from 60 to 275 m (200 to 900 ft) from the northwest to the southwest corners of INEL respectively. Beneath the RWMC the average depth to groundwater is about 177 m (580 ft). The regional direction of groundwater movement within the Snake River Plain aquifer is towards the southwest with an average gradient of 0.76 to 0.94 m/Km (4 to 5 ft/mile). Directly beneath the RWMC, the direction of groundwater movement is to the northeast which is opposite the regional flow. This is a result of recharge from diversion ponds located to the southwest of the RWMC complex. The hydraulic conductivity of the saturated zone averages about 207 m/day (680 ft/mo). The water

supply for INEL is provided by 24 production wells which pump about 9.1×10^9 l/year (2.4×10^9 gal/ year). Approximately one-half of this total is returned to the ground as a result of disposal operations.

A perched water body has been observed beneath the RWMC at a depth of about 65 to 67 m (213 and 219 ft). Two distinct sedimentary layers exist below the RWMC at depths of approximately 34 and 73 m (110 and 240 ft). These sedimentary layers are each approximately 1.5 to 6 m (5 to 20 ft) thick. The surficial sediment layer at the site ranges in thickness from 0 to 4.6 m (0 and 15 feet). The cation exchange capacities of these sediments are 23, 12 and 17 meq/100g for the surface, 34 m, and 73 m sedimentary layers, respectively. The cation exchange capacity of the basalt in the saturated zone is about 10.6 meq/100g.

There are three surface water bodies in the vicinity of INEL: the Big Lost River, the Little Lost River, and Birch Creek. Of the three, only the Big Lost River has significance to INEL, it is the only stream which carries discharge from the INEL area. The average discharge of the Big Lost River is about 2.57×10^8 m^3 (9.07×10^9 ft^3) per year. Geologic data obtained from cores taken in and around the RWMC indicate that the area may have been flooded by the Big Lost River within the past 200 years.

In order to minimize the potential for flooding, a large flood-water diversion system has been developed 900 to 1200 m (3000 to 4000 ft) south and west of the RWMC. The water diversion system consists of four spreading areas into which water is diverted from the Big Lost River. Analysis of stream flow data and use of a computer flood-routing model indicate that a 44 year flood on the Big Lost River would overtop the flood control diversion dam.[14] This potential flood study included recommendations to double the capacity of the diversion system. This recommendation was implemented at the RWMC a few years ago.

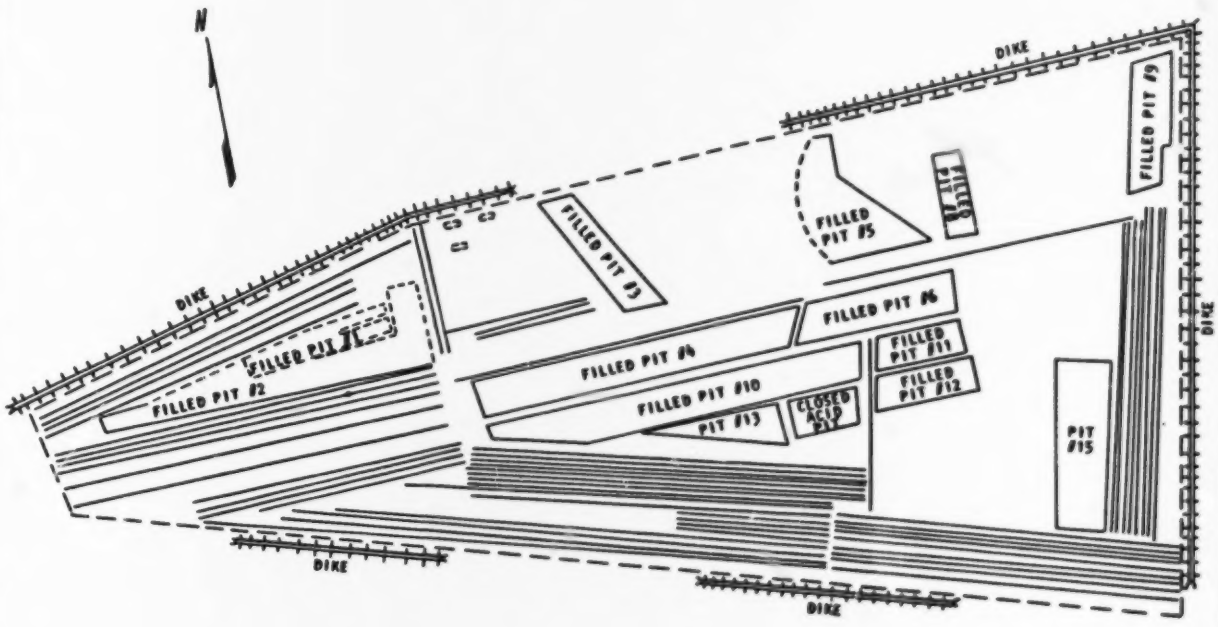
4.4.2 Disposal Experience

Background

Extensive waste management activities are carried out at the Laboratory.[6,12,16-18] High level liquid waste generated from fuel reprocessing operations has been stored in large tanks but for the past several years a program has been carried out to calcine the liquid into a dry solid. Low-activity liquids from INEL operations have been disposed by discharge into seepage ponds and wells. Since INEL was opened, several hundred million gallons of liquid containing mostly short-lived radionuclides have been thus disposed. Disposal and storage of solid low-level and transuranic waste has been principally carried out at the 143 acre radioactive waste management complex (RWMC). An additional 4.1 acre disposal area exists on INEL which was used for disposal of waste generated from clean-up of an accident involving the destruction of the stationary low power test reactor (SL-1).

The RWMC is divided into two fenced sections, namely, the subsurface disposal area (SDA) covering 35.6 ha (88 acres), and the transuranic storage area (TSA) covering about 22.3 ha (55 acres). About 8 ha (20 acres) remains available for use at the SDA and about 17.8 ha (44 acres) at the TSA. The locations of the disposal and storage areas are illustrated in Figure 4-4. Selection of the RWMC site was based on several basic requirements. These requirements included reasonable accessibility (no requirement for extensive road construction), reasonable thickness of unconsolidated sediment (greater than several meters), good cation exchange capacity of disposal media (requiring clay content), a moderately sized parcel of land (tens of hectares), drainage, and reasonably cohesive soils for ease of excavations.

The first solid waste disposal operations at the RWMC began in the summer of 1952. The first waste buried at the RWMC was mixed fission



IDAHO NATIONAL ENGINEERING LABORATORY
SUBSURFACE DISPOSAL AREA

0 200 400
SCALE IN FEET

DAMES & MOORE

FIGURE 4-4

product waste including filters, pipe fittings, glassware and trash. The trenches excavated during the first five or six years of operations were dug down to the basalt using backhoes. The trenches dug during the period 1952 to 1957 were typically 274 m (900 ft) long, less than 2 m (6 ft) wide and generally about 3.7 m (12 ft) deep. The original disposal area was fenced in and covered slightly over 5 ha (12 acres).

The first significant influx of off-site generated waste began in 1954 when waste from the Rocky Flats Facility in Colorado was shipped to INEL. These original waste shipments were probably TRU contaminated waste. In 1957, the SDA was expanded from its original 5 hectares size (12 acres) to its present size of 35.6 hectares (88 acres). This expansion also encompassed an acid disposal pit which had been used since 1954. During the year of site expansion, the volume of waste from Rocky Flats was rising fairly rapidly. After 1957 mixed fission product waste was buried in trenches using the same methods employed previously. In general, during the early and middle period of disposal activity at the RWMC (1952-1969), waste was stacked when possible, however, some waste was randomly disposed of as indicated by later retrieval studies.

In 1961, an additional disposal area was opened on INEL near the SL-1 reactor (located at INEL in the Auxiliary Reactor Area) and was used until 1962. The disposal area was opened after the SL-1 reactor experienced an accidental excursion in January 1961 which destroyed the reactor and contaminated the reactor building. Since much of the waste generated from clean-up of the accident emitted higher than normal levels of gamma radiation, the disposal area was opened to minimize personnel exposures from waste handling and transportation. Two pits and a trench were excavated in this area.

Shortly after expansion of the SDA a system of trench and pit marking was initiated. Concrete monuments were installed along the centerline

at both ends of each trench and at the four corners of each pit. Metal plates containing information on the disposed waste were emplaced on each marker. In 1957 the AEC-ID Manual Chapter 0500-7 required specific organizational and responsibility networks which resulted in the establishment of formal operational procedures at the disposal site. After the implementation of these formal procedures, definitions of routine and non-routine waste were made and specific procedures for each were formulated. Routine waste was defined as any waste emitting less than 500 mR/hr at a 1 m distance, and did not require special equipment and containers. Non-routine waste was defined as that waste emitting over 500 mR/hr at a 1 m distance, or requiring special equipment, special hauling, or special handling. Source material, liquids, and slurries were defined as non-routine wastes.

Other improvements in disposal technology implemented between the closure of the interim use of the RWMC for commercial waste disposal and the AEC directive to retrievably store TRU wastes at the federal sites (1963-1971) included: a) increasing the minimum soil cover over the waste, b) increasing the minimum trench depth, and c) in-situ waste compaction accomplished by dropping a steel plate onto the waste in the trenches. Due to a few incidents of fires in disposal trenches, a program was instituted to cover the waste in the trenches at the end of each working week.

Current activities at the SDA include both underground and aboveground disposal. Low-activity beta-gamma wastes are disposed of in pits ranging from 150 to 300 m (492 to 984 ft) in length, 30 to 45 m (101 to 148 ft) in width, and 2 to 7.3 m (6.5 to 40 ft) in depth. Trenches, 150 to 300 m (492 to 984 ft) in length, 6 m (20 ft) wide, and 4.5 m (15 ft) in depth are employed for disposal of high-activity beta-gamma wastes. Shafts or soil vaults are also used for disposal of high-activity beta-gamma wastes.

The RWMC is equipped with waste compaction and decontamination facilities. At the compaction facility, low-level beta-gamma waste is compacted into bales, and then packaged in fiberboard and plastic bags before transport to the SDA. Beta-gamma contaminated equipment is decontaminated at the decontamination facility. Surface contamination is removed by a high-pressure spray washer, while fixed contamination is removed by abrasive grinding machines. The decontamination facility employs a closed-loop water system using ion-exchange columns for water purification.

Since the 1971 AEC directive to retrievably store TRU waste, the operating practices at INEL (and other DOE sites) have changed appreciably. All TRU storage facilities at INEL are located in the 22.3 ha (55 acres) transuranic storage area (TSA) at the RWMC. These TRU wastes are stored on aboveground asphalt pads which are about 229 m long by 46 m wide (740 by 150 ft). The asphalt pads are composed of a 7.6 cm (3 in) layer of asphalt over a 10.2 cm (4 in) layer of compacted crushed gravel. These asphalt pads are sloped to promote drainage away from the storage areas. Waste stacking is performed under an air support weather shield. Some TRU waste at the TSA is stored in concrete-filled carbon steel storage vaults composed of 7.9 m (26 ft) vertical pipes that are 40 or 61 cm (16 or 24 in) in diameter. These storage vaults are part of the intermediate-level transuranic storage facility (ILTSF).

Programs to exhume older, buried TRU waste have been carried out within air support weather shields. The actual exhumation (referred to as early waste retrieval) is doubly contained within the operating area, i.e., enclosed within a second structure in the weather shield.

Problems Encountered

Problems experienced at INEL have included incidences of minor spills involving surface contamination as well as some fires in early

disposal trenches.[18] As mentioned earlier, the potential for future fires has been considerably reduced through more frequent covering of emplaced waste packages.

More significant incidents have involved flooding of the RWMC and the SL-1 disposal area. In addition to direct discharge from the Big Lost River, local precipitation, overland flow and snow melt waters have contributed to these floods. The RWMC is located in a topographic depression in which water tends to occasionally accumulate. In February 1962, and again in January 1969, snowmelt waters and rainfall combined to produce a partial inundation of the RWMC complex. The flood in the winter of 1962 was brought on by several days of rainfall, which exceeded 40 mm (1.5 in), falling on frozen ground which had been covered with over 200 mm (8 in) of snow. One pit and two trenches (open excavations at the time) were filled with runoff. After a thaw in January 1969 lasting several days, rainfall combined with snowmelt resulted in the second flooding of the RWMC. The damming of a drainage ditch contributed to this second flood.[13,18]

The SL-1 disposal area was briefly flooded in 1962. The flood resulted in transport of uncovered waste to locations outside the disposal area. These transported wastes were successfully recovered.

4.4.3 Discussion

The experience at the RWMC at INEL has been characterized by reasonably good disposal site performance. Both positive and negative natural features of the site contribute to the overall performance of the disposal areas. The negative factors include a demonstrated potential for flooding of disposal areas, moderate subsurface permeabilities, and fractured bed rock. The positive natural factors at the RWMC include reasonably high absorptive capacity of the soils and basalt, lower permeabilities in the vertical direction than in the

horizontal direction, low precipitation rates, high evaporation rates, large depth to ground water, and availability of land area in a relatively isolated location.

The majority of the man-made impositions to the site environment have benefited the overall performance of the RWMC. These man-made changes have included improvements in surface drainage for flood prevention, improved fire prevention measures, improved record keeping, waste segregation procedures, and volume reduction of compressible wastes.

4.5 Savannah River Plant (SRP)

The SRP is located in southwestern South Carolina, adjacent to the Savannah River in Barnwell and Aiken Counties. The SRP occupies about 77,700 hectares of land (192,000 acres). The closest town with a population over 4,000 is Barnwell, South Carolina, located approximately 24 Km (15 mi) from the center of the SRP.

The SRP was established in 1950 by the AEC to produce national nuclear defense materials, and is currently operated for DOE by the E. I. DuPont de Nemours Company. Plutonium and other isotopes are produced using large heavy water reactors. The product materials produced at SRP include ^{60}Co, ^{210}Po, ^{233}U, ^{238}Pu, ^{239}Pu, ^{244}Cm and ^{252}Cf. Support facilites at the Savannah River Plant include heavy water extraction plants, nuclear fuel and target fabrication centers, and fuel processing plants. Chemical processing of irradiated fuels produces substantial quantities of waste materials.

4.5.1 Site Environmental Characteristics

SRP is located in the upper Atlantic Coastal Plain Province.[2,19-24] The site is underlain by a sequence of unconsolidated and semiconsol-

idated sediments of Cretaceous, Tertiary, and Quaternary ages. These sediments unconformably overlie basement rocks which consist of gneiss and schist. The cation exchange capacities of these sediments range from 0.9 to 15.2 meg/100g.

The climate at SRP is relatively temperate, with mild winters and long summers. This area of South Carolina, while subjected to continental weather influences, is protected by the Blue Ridge Mountains from the more vigorous winters prevailing in states to the west (e.g., Alabama, Tennessee, Georgia). The average winter temperature at the SRP is 8.9°C (48°F), and the average summer temperature is 26.6°C (80°F). The annual average temperature is 18.3°C (65°F), with a normal range of 6.6°C (20°F). The average annual precipitation at SRP is 1193 mm (47 in). The highest and lowest recorded annual precipitation rates are 1874 mm (73.8 in) and 711 mm (28 in), respectively. The average hourly wind velocity recorded for Augusta, Georgia (about 40 km (24.9 miles) to the northwest) between 1950 and 1955 is 10.2 km per hour (6.4 mph). The prevailing winds are from the northwest and west to southeast. The SRP is occasionally subjected to severe storms and the influence of passing hurricanes. Some tornadoes have been sighted in the general vicinity of the plant; however, no significant tornado damage has occurred to any SRP facilities. The SRP facilities are located within a region where moderate damage to buildings from seismicity might result.

The major surface water body in close proximity to the SRP is the Savannah River. Of the five tributaries which feed the Savannah River in the vicinity of the SRP, two tributaries are considered significant in their relationship to the SRP disposal area. Four Mile Creek, which forms the southern surface-water boundary of the disposal area, flows southwestward for about 24 km (15 miles) into the Savannah River. The second tributary, Upper Three Runs Creek, forms the northwestern surface water boundary of the disposal area.

The primary source of groundwater recharge in the immediate vicinity of the SRP disposal area is precipitation, with direct infiltration to the groundwater occurring in the area between the two creeks. Estimates indicate that 508 to 560 mm (20 to 22 inches) of precipitation per year recharges to the groundwater in this manner.

Although the SRP is underlain by at least six sedimentary formations, the Barnwell and McBean Formations contain the saturated zone of interest to this discussion. The disposal area is located close to a groundwater divide in the Barnwell Formation, on the north side of the divide, the groundwater flows northward towards Upper Three Runs Creek, on the south side of the divide, the groundwater flows southward toward Four Mile Creek. The horizontal ground water movement in the Barnwell Formation is between 2.8 and 4.5×10^{-5} cm/sec (.08 and 0.13 ft/day). Ground water movement in the McBean Formation probably ranges from 3.4 to 5.2×10^{-5} cm/sec (0.01 and 0.15 ft/day).

In the vicinity of the SRP disposal areas, the normal depth to the water table (which occurs primarily in the Barnwell Formation) ranges from 6 to 18 m (20 to 60 ft). The mean depth of the water table in the disposal area itself is at about 45 feet, with a normal fluctuation of about 2 feet. It is important to realize that groundwater in the Barnwell Formation is not strictly under watertable conditions in the sense of being unconfined. The unsaturated zone in the disposal area is made up entirely of the Barnwell Formation. It consists primarily of clayey sand with some sandy clay, and includes sand layers of limited lateral extent. The sandy clay and low-permeability clayey sand layers in the unsaturated zone tend to partially confine the ground water in this formation at the disposal area, and several small areas of perched water are present in the disposal area.

Water in the McBean Formation is semi-confined, and water levels tend to be somewhat lower than the water-table elevations in the overlying Barnwell Formation. Thus, downward movement occurs to some extent

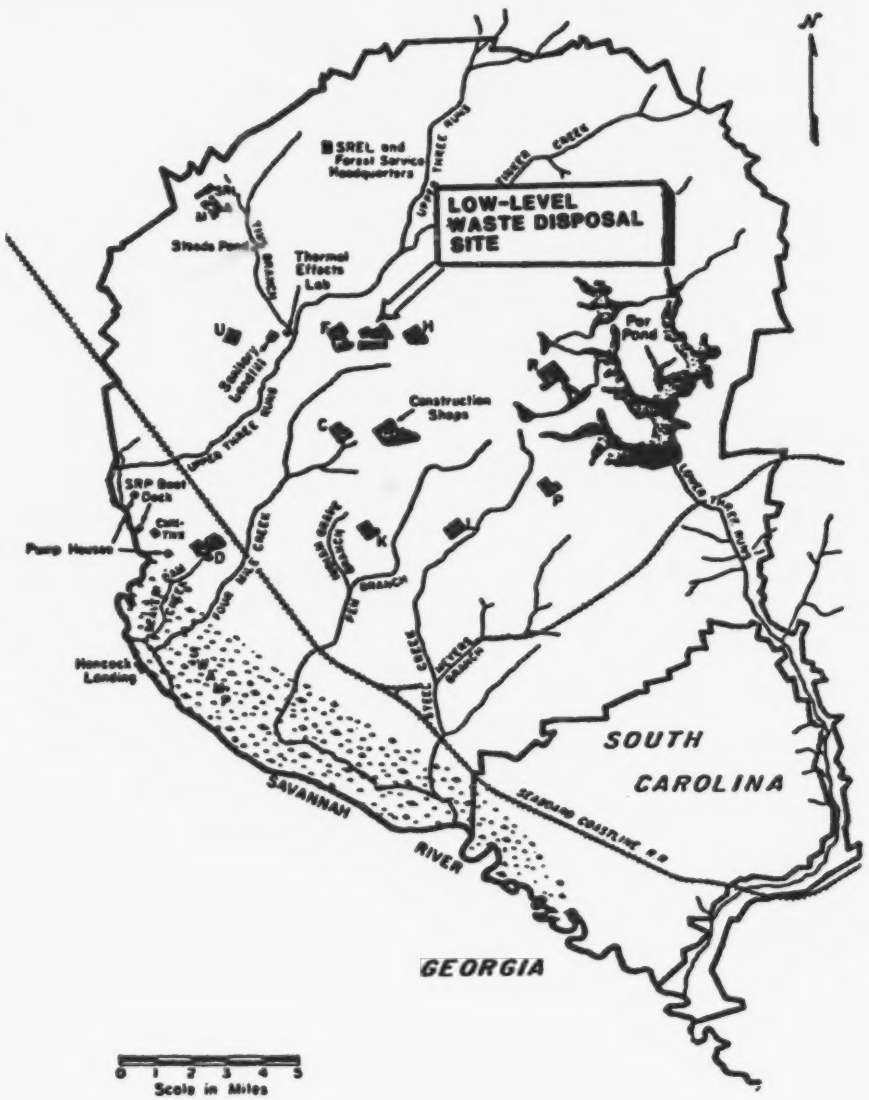
from the Barnwell to the McBean Formation. While the Barnwell Formation is not used for public supply, the McBean Formation serves as a minor source of domestic and municipal water in the region. Several public supply wells at Barnwell, 27 km (17 miles) to the east, and one well at Williston, 26 km (16 miles) to the northeast, tap the McBean Formation. The Tuscalosa Formation (generally over 100 meters (328 ft) below the disposal area) serves as the primary aquifer for municipal and industrial water supply in the area.

4.5.2 Disposal Experience

Background

Waste disposal and storage operations have been carried out at SRP since 1953 (Figure 4-5).[6,19,21,24] The types of waste stored and disposed at the SRP are quite variable and include such items as:[21] (1) contaminated equipment (obsolete or failed tanks, pipes, process equipment), (2) laboratory and operating waste (e.g., gloves, protective apparel, analytical waste, decontamination residues, glassware), (3) non-fuel reactor hardware, (4) spent lithium-aluminum targets (5) contaminated oil (from pumps in tritium facilities), (6) spent ion-exchange resins, and (7) "special shipments." Included in the "special" waste category are ^{238}Pu process waste from the Mound facility and LASL, and debris (including soil) from two U.S. airplane accidents involving nuclear weapons.

The disposal and storage areas at SRP occupy about 78.9 ha (195 acres) of land. Disposal activities have been performed at two continguous sites. The first site encompasses about 31 ha (76 acres) and was filled in 1972. More recently, waste disposal and storage has been carried out at an adjacent site encompassing about 48 ha (119 acres). Typical disposal trenches at the SRP disposal area are 215 m (700 ft) long, 6 m (20 ft) wide, and 6 m (20 ft) deep. Waste is placed into segregated trenches according to the surface radiation levels of the



SAVANNAH RIVER PLANT

DAMES & MOORE

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FIGURE 4-5

waste packages. After waste emplacement, a minimum soil cover of 1.2 m (about 4 ft) of soil is added to reduce surface radiation levels to less than 6 mr/hr.

TRU waste was originally disposed at SRP in a non-retrievable manner. In 1965, however, TRU waste began to be segregated into a retrievable and a non-retrievable category with additional containment provided for retrievable waste. Waste containing greater than 0.1 Ci per package was placed into concrete containers and buried. Wastes too large for the containers were incapsulated in concrete. Waste containing less than 0.1 Ci per package was disposed in low activity "alpha" trenches.

More recently, wastes which contain more than 10 nCi/gm of TRU isotopes are stored on 0.3 m (12 in) thick reinforced concrete pads measuring 18 m (59 ft) in width and 46 m (151 ft) in length. These pads are sloped for drainage. The waste stored on these pads is packaged in concrete containers, steel boxes, and galvanized steel drums. As a pad is filled, the waste is covered with sand, soil, plastic sheeting, and additional overburden to a depth of 1.2 m (4 ft). On top of the overburden, when the pad is filled to capacity, a layer of asphalt and a final layer of soil are added, followed by seeding of this surface for revegetation Bulky contaminated machinery and wastes having high surface radiation levels are stored in earthen trenches.

In addition, the disposal area contains 8 underground tanks holding several thousand gallons of degraded solvent from the site fuel reprocessing facilities. As of 1977, about 150,000 gallons containing about 45 Ci of TRU radionuclides have been stored. The liquid level in the 8 tanks are checked on a weekly level and studies are ongoing to develop a means of disposing of the solvent.

Finally, a number of seepage basins at different locations at SRP

have been and are used to dispose of low-activity liquids. Liquid discharged into the seepage basins migrates through the groundwater and, after several years of travel, into streams running through the site. The only isotope in significant quantities reaching the streams is tritium, which moves at the speed of the groundwater, and resulting streams concentrations are well within limits specified in ERDAM-0524.

Problems Encountered

Over 20 years of operation of the disposal area at SRP, there have been a few relatively minor incidents, none of which were reponsible for significant off-site impacts.[19] For example, there have been some minor fires in disposal trenches plus several occasions in which site grounds have become contaminated. In all cases, however, the contaminated soil was removed and disposed. Two of the latter incidents involved overflow of water from open trenches. In one case in 1965, a trench containing rainwater was backfilled with soil, which displaced the contaminated rainwater and caused it to overflow the trench. In another case in 1973, rainwater filled an open trench, overflowed, and contaminated about 3000 ft^3 of adjacent ground. Other incidents involved 2 spills of low-activity water and 9 spills of contaminated solvent. In another case, subsidence of a trench cover resulted in temporary exposure of a disposed waste container. Finally, in two cases earth moving equipment accidently cut into disposal trenches, temporarily exposing disposed waste and temporarily contaminating small areas.

There has also been 10 recorded incidents in which radioactivity has been taken up by plant roots.[19] In these cases, the vegetation was removed and disposed. Plant uptake has since been controlled through such measures as increasing the thickness of earthen fill covering disposal trenches, destroying long-rooted vegetation, and substituting short-rooted vegetation.

4.5.3 Discussion

In summary, the experience at the SRP has been characterized by reasonably good disposal site performance. It can also be seen that both positive and negative natural features at the site contribute to the overall performance of the disposal area. The positive natural features include reasonably high absorptive capacity of the soils, moderate depth to the groundwater table (about 12 m), and a reasonable availability of suitable land area for disposal. Among the negative natural features are high precipitation rates (1193 mm/yr) and local zones of moderate permeability. Overall the positive natural features have significantly overweighed the negative features; the overall disposal performance has been good.

4.6 Other Government Disposal Sites

Radioactive waste has also been disposed or stored at several other DOE sites. These sites have included: the Pantex Plant (Amarillo, Texas), Sandia Laboratory (Albuquerque, New Mexico), the Nevada Test Site (north of Las Vegas, Nevada), the Feed Materials Production Center (Fernald, Ohio), the Niagara Falls Site, (Niagara Falls, New York), the Oak Ridge Gaseous Diffusion Plant (Oak Ridge, Tennessee), the Oak Ridge Y-12 Plant (Oak Ridge, Tennessee), the Paducah Gaseous Diffusion Plant (Paducah, Kentucky), the Portsmouth Gaseous Diffusion Plant (Piketon, Ohio), and the Weldon Springs Facility (St. Charles County, Missouri). These DOE facilities have been engaged in activities such as energy research, weapons research, uranium enrichment source material processing, fuel fabrication, or weapons production.[6,25]

Pantex Plant

The Pantex Plant is located approximately 27 km (16.8 miles) northeast

of Amarillo Texas. The plant was built in 1942 to produce conventional bombs and shells. Current activities include fabrication of chemical explosive components for nuclear weapons, nuclear weapons assembly and disassembly, nuclear weapons modification and repair, and surveillance testing and disposal of chemical high explosive and non-radioactive components. The storage area at the Pantex Plant occupies about 1.4 hectares (3.5 acres) of the total Pantex site, which encompasses about 3,683 ha (9100 acres).

The Pantex Plant is underlain by caliche and shale. The surficial soils are predominantly silt clays with low primary permeability, and the soils in the vicinity of the storage area are reported to have high absorptive capacities. The depth to groundwater at the site is about 120 m (393 ft). The closest surface water is a small ephemeral stream located about 14 km (8.8 miles) from the plant. The annual precipitation rate at the Pantex Plant is about 508 mm (20 in).

All radioactive waste buried at the Pantex Plant has been done so as to ensure retrievability over a period of 20 years. The radioactive waste is stored either in vertical concrete cylinders which measure about 1.8 m (6 ft) in diameter and 6.1 m (20 ft) in depth, or in trenches which measure about 30.5 m (100 ft) in length, 4.3 m (14 ft) in width, and 4 m (13 ft) in depth. Both the waste stored in cylinders and in trenches are covered with 1.8 m (about 6 ft) of compacted soil. Staging for waste storage operations is done in an "igloo" (weather shield and warehousing structure) adjacent to the storage area. At the waste generation point, the waste is packaged for storage in plastic bags and overpacked in fiberglass wooden boxes or in 5 gallon paint cans. TRU contaminated waste is not generated at the Pantex Plant on a routine basis. TRU waste from non-routine sources is segregated from other wastes, packaged in fiberglass boxes, and stored in a separate trench. As of 1977, the current annual waste burial rate was 1.4 m^3 (49 ft^3), and the volume contained about 134 kg (295 lb) of uranium.

Sandia Laboratory

The Sandia Laboratory is located along the foot of the Manzano Mountains near Albuquerque, New Mexico. The disposal site currently used at the Sandia Laboratory measures about 0.6 hectares (1.5 acres). This disposal site is located in an environmental test area known as Tech Area III. An older disposal site (closed in 1960) is located in an explosive test area (Tech Area II) and occupies about 0.11 hectares (0.27 acres) of land. The disposal sites at Sandia are underlain by unconsolidated alluvium. The surface soils are predominately alluvial clays, silts, and sands, which have moderate permeabilities and absorptive capacities. The annual precipitation at Sandia is about 203 mm (8 in). The depth to ground water is about 145 m (475 ft). The only surface water near the site is a highly ephemeral stream.

The active disposal site has been divided into three separate functional areas: one for disposal of classified nuclear weapons components, one for disposal of bulky debris, and one for future expansion. The two methods of disposal employed at Sandia Laboratories are trench and pit disposal. Low activity or suspect radioactive waste is emplaced in trenches which typically measure 55 m (180 ft) in length, 11 m (36 ft) in width, and 4 m (13 ft) in depth. This low activity waste includes decontamination debris, surplus contaminated equipment, experimental structures used in contaminated areas, solidified liquids, and high efficiency particulate air (HEPA) filters. All radioactive devices with security classification, uranium machine wastes, wastes which are potential fire hazards, and sources with greater than 10 uCi are disposed in pits roughly measuring about 3 m (10 ft) in length, about 3 m (10 ft) in width, and 8 m (26 ft) in depth.

Before the AEC required retrievable storage for TRU waste, TRU contaminated debris from nuclear weapons tests was disposed in a non-retrievable form. After the requirement for retrievable storage was

instituted, all TRU waste generated at Sandia was transported to another DOE storage facility. At the present time, the Sandia Laboratory does not generate TRU wastes. As of 1977 the cumulative inventory of waste at Sandia Laboratory had a volume of 1322 m^3 (46,700 ft^3), and the cumulative decayed activity buried was 2.4 kCi.

Nevada Test Site (NTS)

The Nevada Test Site occupies a land area of 371,158 hectares (917,119 acres) in Nye County, Nevada. Over 40% of this land area has been used for nuclear testing programs; the remaining land area offers a wide variety of potential locations for waste management operations. As of 1977 approximately 81 hectares (200 acres) have been used for waste storage or disposal.

The disposal areas at NTS are underlain by alluvial material and volcanic tuff. The surface soils at the NTS disposal areas generally are composed of alluvium and weathered tuff. The primary permeability of this material is moderate to low. The absorptive capacity of the surface soils is considered to be moderate. The depth to groundwater at NTS ranges from 200 to 460 m (656 to 1510 ft). Surface streams do exist at NTS but they are quite ephemeral with drainage into closed basins. The annual precipitation at NTS is about 102 mm (4 in).

Seven disposal and storage areas have been used at the NTS for radioactive waste. These seven areas include the Area 5 radioactive waste management site (RWMS), the R-MAD (reactor-maintenance, assembly, and disassembly) RWMS, the U3ax crater, the U3fi drillhole, the U2bu crater, the U8d potshot drillhole, and the Horn Silver mineshaft. Another 26 sites at NTS have been used in the past for surface storage of radioactive waste but are no longer active. Wastes such as nuclear test wastes, reactor cores, and parts from a large exhaust deflector

have been stored at these inactive sites, and may be transferred to other locations in the future. In addition, there are 10 seepage basins at NTS which have been used for disposal of low-activity contaminated liquids generated from mining and decontamination activities.

The R-MAD facility occupies 22.3 hectares (55 acres) of land and is used to store reactor hardware. In the past, the R-MAD facility has been used for surface storage of radioactive waste and hardware from the nuclear rocket development program. The Area 5 RWMS is used for storage activities. It occupies about 15.7 ha (38.8 acres) of land and is used for storage of tritium waste, low activity TRU waste, and potentially reusable activated or contaminated hardware or equipment. The Area 5 RWMS is also employed for disposal activities. Waste disposal has been accomplished in trenches which typically measure 90 to 180 m (295 to 590 ft) in length, and 3.2 m (10 ft) in both width and depth.

The U3ax crater is 129.5 m (425 ft) in diameter and 18.3 m (60 ft) deep, and was created from a past underground nuclear test. This crater is used primarily for large unpackaged waste, and has over 40,000 m^3 (1.4 million ft^3) of available disposal capacity left. The U3fi drillhole is 1.8 m (6 ft) in diameter, and has been plugged at the 240 m (787 ft) depth. This drillhole was initially intended for emplacement and firing of a nuclear test device, but this intention was abandoned. The drillhole is now used for disposal of classified waste such as drilling core samples containing contaminated debris from weapons tests.

The U2bu crater was originally about 230 m (755 ft) in diameter and 31 m (102 ft) deep, and has been used for disposal of contaminated drilling mud. This crater is nearly full to capacity with waste mud. The U8d potshot drillhole is used for the disposal of low activity contaminated liquid waste. The Horn Silver mineshaft is an abandoned

mineshaft that has been used for disposal of classified radioactive waste. The majority of the waste disposed in this abandoned mineshaft is from the nuclear ramjet engine test series (Project Pluto). At a depth of 128 m (420 ft), a concrete plug has been poured over the waste and a concrete collar pad and steel cover and lid have been installed in the shaft. In 1977, the unused volume in the mineshaft totalled about 700 m^3 (25,000 ft^3).

Feed Materials Production Center

The Feed Materials Production Center (FMPC) is used for the production of purified uranium metal and compounds used at the other DOE facilities. The FMPC occupies a 424 hectares (1048 acres) site in Fernald, Ohio about 16 km (10 miles) northwest of Cincinnati, Ohio. Some thorium production work is also performed at FMPC.

The FMPC site is underlain by shale and limestone. Surface soils at FMPC are comprised of glacial and fluvial sediments. The primary permeability of these soils is low, while their absorptive capacities are relatively high. The depth of ground water beneath the site is 9 to 18 m (30 to 60 ft) and the aquifer is located within a formally buried river channel. A small perennial stream exists on site.

Most of the radioactive solid waste at FMPC is generated from the neutralization of acidic waste solutions. Sludges and filter cake which are collected from the neutralized wastes are deposited in chemical waste pits. Two types of long-term storage facilities are used at FMPC: tanks and chemical waste pits.

There are four tanks used for waste storage (two are referred to as "K-65" tanks and two as metal oxide tanks). The tanks are cylindrical and measure 24.4 m (80 ft) in diameter and 8.2 m (27 ft) in height. The walls of these tanks are 20.3 cm (8 in) thick, and are composed of pre-stressed concrete. High tensile strength steel wire wraps the

walls, the wire is covered with a 1.9 cm (3/4 in) grout coating. A soil embankment surrounds the tanks to provide added protection. The K-65 tanks belong to the African Metals Corporation, and contain refinery residues from the processing of African (Zaire) pitchblend ores (processing of these ores was discontinued in 1958). The tanks are retained at FMPC under a lease contract which runs through 1983. One of the two metal oxide tanks contains radioactive wastes. The wastes in this metal oxide tank are residues from the processing of ore concentrates.

The chemical waste pits have been given numbers based on the chronological order of their construction. The pits are given a "wet" or "dry" designation based on the type of waste placed into the pit. Through February 1977, the inventory of natural and enriched uranium in pits 1 through 5 included 3,135,990 kg (6.9 million lbs).

Pits 1, 2 and 4 are excavations lined with 46 to 61 cm (18 to 24 in) of very low permeability clay. The depths of pits 1 and 2 are 3.2 and 4.0 m (10 and 13 ft), respectively. Both pits have been backfilled and mounded to provide surface drainage from the disposal area. Pit 4 has a depth of 7.3 m (24 ft) and is used for the disposal of dry solids.

Pit 3 has been used for disposal of the solids from neutralized waste slurries. The original capacity of Pit 3 was 174,110 m^3 (6.1 million ft^3). The pit has been mostly filled; the remaining capacity has been used for the disposal of filter cake. Upon completion this pit will be backfilled, mounded, and seeded for erosion protection.

Pit 5 is a 87,929 m^3 (3.1 million ft^3) rubberlined basin. The surface area of the basin is 1.5 hectares (3.7 acres) with a depth of 7.6 m (25 ft). Pit 5 has been used for the disposal of liquid wastes which result from the processing of uranium and thorium.

Niagara Falls Site

The Niagara Falls Site, owned and operated by DOE, is inactive and in a "caretaker" status. The site is located in Niagara County, New York. The site is underlain by shale, and surface soils are composed primarily of glacial till. The primary permeability of these surface soils is considered to be very low, and the absorptive capacities of the soils are considered to be high. The depth to groundwater at the Niagara site ranges from 0 to 10 m (0 to 33 ft). A small perennial stream exists onsite.

Radioactive wastes at the Niagara site are either stored in buildings or disposed in aboveground waste mounds. The wastes stored and disposed at this site are chiefly residues from the processing of Belgian Congo pitchblende concentrates generated during the early days of the Manhattan Project. The majority of the minerals stored in the buildings at the Niagara site belong to the African Metals Corporation and are stored in leased buildings.

The aboveground waste mounds contain residues, iron cake, and contaminated soil. The mounds have been covered with clean soil and seeded for erosion protection. The pitchblende residues include 7.5 million kg (7,500 metric tons) which average about 0.1% U_3O_8. The iron cake waste has a mass of 140 metric tons containing about 0.4% U_3O_8. The 11,469 m^3 (404,970 ft^3) of soil waste was derived from a decontamination operation. The radioactive wastes stored in buildings at the site include 1.6 million kg of residues, 7.5 million kg of filter cake, 1.7 million kg of sludges, 130,000 kg of 1% U_3O_8 wastes, and 1815 kg of Middlesex sands with a U_3O_8 content of approximately 4%.

Oak Ridge Gaseous Diffusion Plant

The Oak Ridge Gaseous Diffusion Plant (ORGDP) is located in eastern Tennessee near the city of Oak Ridge. The ORGDP occupies about 259

hectares (640 acres) of land area. The primary purpose of the work at the ORGDP is to enrich the quantity of ^{235}U in natural uranium compounds relative to the more dominant ^{238}U. Uranium hexafloride is processed through a large series of diffusion cascades to achieve enrichment of the lighter uranium isotope.

The ORGDP facility is underlain by subsurface formations similar to those at the ORNL disposal areas. The site is underlain by both shale and limestone, and surface soils are generally composed of weathered shale and limestone. The primary permeability of these surface soils is considered to be low. The absorptive capacity of these soils is high. The depth to groundwater ranges from 0 to 20 m (0 to 66 ft). The ORGDP is located in proximity to the Clinch River (a large perennial stream).

The majority of the LLW stored or disposed of at the ORGDP is material contaminated with uranium, ^{237}Np, ^{239}Pu, and ^{99}Tc. Five sites have been used for waste management at the ORGDP. These sites include a retention basin, a scrap metal yard, a contaminated waste disposal area, an old classified disposal area, and a new classified disposal area.

The retention basin measures 213.4 m (700 ft) in length, 15.2 m (50 ft) in width, and 1.8 m (about 6 ft) in depth. It is used for the disposal of both radioactive and non-radioactive sludge, including dredged material from holding ponds. As of 1977, approximately 1147 m^3 (40,500 ft^3) of dewatered sludge had been placed in this basin. This volume of sludge contains about 18 Ci of radioactivity, primarily uranium and ^{99}Tc.

The scrap storage yard occupies 8.9 ha (22 acres) of land. The scrap metals stored at this yard include stainless steel, steel, copper, nickel, aluminum, and alloys which total between 2.7 and 4.5 million kg (5.9 million lbs) of mass. A fraction of the yard is used for

storage of metals that have been contaminated with uranium, or that exhibit surficial alpha or beta-gamma activity.

The contaminated waste disposal area is a small 1.1 ha (2.7 acres) area with over 60 separate disposal locations. These disposal locations include both trenches (measuring 36.9 m in depth, 3.4 m in width, and 0.9 m in depth), and shafts (measuring 3.7 m in depth and 0.9 m in diameter). As of July 1975, this disposal area contained over 1000 m^3 (35,310 ft^3) of uranium-contaminated material and 68 m^3 (2400 ft^3) of thorium contaminated material. Other materials disposed at this disposal area included beryllium chips, boron, uranium hexafluoride cylinders, uranium compounds, and thorium compounds. This material has been estimated to contain about 14 Ci of radioactivity. This disposal area was placed into inactive status in 1976.

Two additional disposal areas exist which have been used for the disposal of classified material. The old classified disposal area occupies about 1.5 ha (3.7 acres) of land. The new classified disposal area occupies about 8.9 ha (22 acres).

Oak Ridge Y-12 Plant

The Oak Ridge Y-12 Plant is a government facility occupying about 427 ha (1055 acres) in Bear Creek Valley about 4 to 8 km from Oak Ridge, Tennessee. The subsurface geology and surface soils at the Y-12 Plant are very similar to those at the ORNL and ORGDP disposal areas, as are the surface and subsurface hydrology and meteorology. Non-classified LLW generated at the Y-12 plant is disposed of at the two disposal areas located about 2.9 km (1.8 miles) from the main plant. The classified material disposal site is located within the main plant.

The disposal area designated as 1-A is used for the disposal of materials contaminated with depleted uranium, such as particulate

filters, machine turnings and metal drums. As of 1977, approximately 9 million kg of these contaminated materials were being disposed of annually. The area designated as 2-B is used for the storage of pure, depleted uranium. As of 1977 about 730,000 kg of uranium had been buried in the trenches, which typically measure 5.8 m (19 ft) in depth and 2 m (8 ft) in width. The disposal area designated as 2-C is used for disposal of materials contaminated with enriched uranium and natural thorium. The annual rate of disposal at disposal area 2-C is about 450,000 Kg.

Paducah Gaseous Diffusion Plant

The Paducah Gaseous Diffusion Plant (PGDP) is another facility whose purpose is to enrich natural uranium. The PGDP occupies about 303 ha (748 acres) of land near Paducah Kentucky. The PGDP is underlain by limestone, and the surface soils generally consist of alluvium and loess. The primary permeability of the surface soils is low, and the absorptive capacities of these soils is high. The depth to ground water is about 18 m (59 ft). A small perennial stream exists on site. The annual precipitation rate at the PGDP is about 1140 mm (45 in).

At least 14 areas have been used for waste management at the PGDP. These 14 areas include 7 miscellaneous waste disposal areas, 1 single item disposal area, 2 metal scrap yards, 1 aluminum waste disposal area, 1 uranium waste disposal area, and 2 concrete disposal areas.

The seven miscellaneous waste disposal areas include Area M, Area C-404, Area B, C, and G, Area F-C 340, and Area A. Area M is an older disposal area consisting of two pits occupying an area of about 0.08 ha (nearly 0.2 acres). The older and larger of the two pits was used for the disposal of miscellaneous contaminated and noncontaminated trash and equipment. The smaller pit was used for the disposal of scrap metal. Both pits are covered with 0.6 to 0.9 m (2 to 3 ft)

of soil. The waste disposed in these two pits is primarily contaminated with natural and depleted uranium.

Disposal Area C-404 is a converted holding pond which was formerly used for the disposal of uranium-contaminated magnesium fluoride slag and rejected uranium tetrafluoride. The original pond was constructed with an at-grade clay bottom, and with clay lined dikes which were 1.8 m (6 ft) high. The pond has been filled, covered and mounded with silty clay. Uranium waste packaged in drums is now placed on top of the backfilled pond. When the area is filled with drums, a clay cover will be emplaced.

Disposal Areas B, C and G were used between 1958 and 1962 for disposal of noncombustible trash, and noncombustible material and equipment. The disposal pits in these areas were dug to a depth of 1.8 to 2.1 m (6 to 7 ft), and were all covered with 0.9 to 1.2 m (3 to 4 ft) of soil. These three disposal areas occupy about 0.2 ha (0.49 acres) of land.

Disposal area F-C 340 occupies about 0.06 ha (0.15 acres), and has been used for the disposal of miscellaneous contaminated material, equipment, and scrap material. The material buried in this area is covered with about 0.9 m (3 ft) of soil. Disposal area A consists of a single trench measuring 83.8 m (275 ft) in length, 20.7 m (68 ft) in width, and about 3.7 m (12 ft) in depth. This disposal trench has been used for the disposal of miscellaneous non-combustible trash, aluminum and steel shavings, and contaminated bulky equipment. The filled disposal trench is covered with 1.2 m (4 ft) of compacted clay and gravel. Disposal area L is a small excavation containing a single cold trap (uranium hexafluoride condensers) buried in 1968 at an approximate depth of 1.8 m (6 ft).

There are two metal scrap yards at the PGDP occupying about 1.0 ha (2.47 acres) of land. The smaller of the two yards has been used for

the storage of contaminated scrap metal from plant operations. The larger yard is used for the disposal of classified scrap metal. These materials are placed into a 2.4 m (8 ft) deep pit, and then covered with 1.2 m (4 ft) of soil.

The aluminum waste disposal area, Area J, occupies an area of about 0.04 ha (nearly 0.1 acres) and has been used for the disposal of aluminum scrap (including nuts and bolts) in drums. These materials are probably contaminated with natural, depleted and enriched uranium as well as with neptunium and plutonium. The contamination levels are believed to be below 10 nCi/g.

The uranium waste disposal area, Area C-749, occupies an area of about 0.3 hectares (0.74 acres), and has been used since 1957 primarily for disposal of pyrophoric material such as uranium metal in the form of turnings, shavings, and dust. The scrap metal is buried in a pit and covered with 1.2 m (4 ft) of soil. The two concrete disposal pits occupy an area of about 0.03 ha (0.07 acres) of land, and have been used for the disposal of contaminated concrete debris. The disposed material has been covered with 0.9 m (3 ft) of soil.

Portsmouth Gaseous Diffusion Plant

The Portsmouth Plant is the third of three gaseous diffusion plants in the United States used for the enrichment of uranium isotopes. The Portsmouth Plant occupies a 1620 hectares (4000 acre) reservation near Piketon, Ohio. The site is underlain by sandstone and shale, and the surface soils generally consist of alluvial and glacial deposits. The primary permeability of these soils is low, and their absorptive capacity is high. The depth to groundwater at the plant is 11 m (36 ft). A small, perennial stream exists onsite. The annual precipitation rate at the site is about 1020 mm (40.2 in).

Four areas have been used for waste management at the Portsmouth

Plant: a warehouse, a surface storage area, a classified waste area, and a burial area. The warehouse occupies an area of about 0.8 ha (2 acres). It is used for storage of uranium hexafluoride (UF_6) in cylinders; nonfluorinated materials such as uranium solutions, UO_3, and U_3O_8; and radioactive plant waste including solid residues from uranium recovery operations, sodium fluoride, magnesium fluoride, contaminated alumina, and various contaminated classified materials. These wastes are stored in the warehouse until sufficient volume accumulates to warrant disposal.

The surface storage area measures 76.2 m by 41.5 m, and is used to store small scrap metal items. These scrap items include brass, stainless steel, nickel, morel and copper. These metals are decontaminated prior to storage and are kept for their high scrap resale value. The classified waste area is used for retrievable storage of such items as barrier tube sheets, floor sweepings and steel parts.

The burial area is a 2 ha (5 acres) area used for the storage and disposal of unclassified contaminated waste. The material stored at the burial area is predominately large pieces of metal or equipment which have fixed surface contamination and are stored in 55-gallon drums. The materials disposed in trenches at the burial area fall into two categories. The first category includes uranium-bearing solids such as incinerator ash, filter cake, alumina, sodium fluoride and magnesium fluoride. Wastes in the first category contain unranium in concentrations which are not considered economically recoverable. The second category consists of suspect or slightly contaminated scrap metal. As of 1977, about 279 m^3 of waste containing about 2700 kg (6000 lbs) of uranium had been buried at the Portsmouth Plant.

Weldon Springs

The Weldon Spring facility is located in St. Charles County, Missouri. The Weldon Springs site is underlain by limestone and the surface

generally consists of clay and weathered limestone. The depth to ground water at the site is approximately 18 m (59 ft) with the regional aquifer lying some 200 m (656 ft) below the ground surface. The permeability of the surface soils is low and their absorptive capacities are high. A small perennial stream flows through the site. The annual precipitation rate at the Weldon Springs site is about 930 mm (36.6 in).

There are two separate disposal facilities at the Weldon Springs site. Radioactive wastes are no longer generated at the Weldon Springs facility, and activities at the disposal areas are in a caretaker status. The two disposal areas at Weldon Springs include a quarry and a group of four raffinate pits which occupy a total area of about 24.7 ha (61 acres).

The quarry has been used for disposal of chemical and radioactive wastes. Before the AEC (now the DOE) acquired the site, the Department of the Army used the quarry for disposal of TNT-contaminated scrap metal. Beginning in 1959, the AEC started using the quarry for the disposal of drummed thorium residues.

The four raffinate pits have a total capacity of 492,700 m^3 (17.4 million ft^3). A total waste volume of 168,102 m^3 (593,000 ft^3) has been placed in these pits. The wastes placed in these pits was primarily neutralized raffinates (slurries) from the uranium recovery operations once performed at the Weldon Springs Production Center.

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5.0 SUMMARY AND LESSONS LEARNED

Over the past 35 years, considerable experience has been gained at both government and commercial disposal facilities. This experience has often been negative, and from this negative experience, a number of improvements have been implemented. Some of the negative experience at government and commercial disposal sites has included biota intrusion; lack of sufficient care in packaging LLW in compliance with DOT regulations for transportation; problems with quality assurance and management control; contamination of ground surfaces; siting in areas that are geologically so complex as to preclude accurate prediction of site performance; flooding; disposal below the ground water table; fires; accumulation of water in the disposal trenches; and disposal in areas of high topographic relief making surface water management a concern.

Some of the positive experiences and practices implemented as a result of past experience include improvements in water management programs at humid sites; better record keeping; better control over site surface contamination; more waste compaction and better trench covers; more extensive inspection and enforcement programs by regulatory agencies; better waste handling and emplacement techniques such as segregation and stacking; specific closure conditions for some of the sites, and others.

In general, the performances of LLW disposal sites have been marginal to very good and the sites have been able to provide short-term protection against harmful effects of radioactive materials. Although shallow-land burial has been the principal disposal method over the years, several near-surface variations have been successfully used. These variations have included the use of caissons, slit trenches, and boreholes for higher activity wastes, use of concrete vaults for storage and disposal of TRU and low-level waste, and intermediate depth burial for cladding hulls.

Problems have been encountered at several sites although the health and safety of the public has not been jeopardized. Rather, the most significant impacts of the problems experienced have been increased maintenance costs and higher probable levels of long-term social committment. Furthermore, there are unresolved questions about the long-term performance of some of the sites.

Several important lessons, which can be applied to future practices, can be derived from the past disposal practices. These lessons learned are discussed below in two sections: an overview section which presents general principles applicable to LLW disposal, and a discussion section which details the three principal controlling mechanisms for protection of the human environment.

5.1 Overview

The goal of LLW disposal is the protection of the human environment. It is necessary to separate the long-term protection of the human environment from the short-term since they involve different levels of scientific understanding and different levels of control. In each case, the protection of the human environment can be achieved by minimizing the radiological and chemical impacts, as well as by minimizing the socioeconomic impacts. These concepts are illustrated in Figure 5.1 together with the controls that can be utilized to achieve these goals.

The long-term protection of the human environment can be accomplished through controlling the long-term performance of (1) the waste form, (2) the disposal site (including site selection, design, and operations), and (3) the institutional aspects of the disposal system. In order to minimize the long-term radiological and chemical impacts, these controls may be applied in the form of barriers to minimize the interaction between the waste and transfer agents -- e.g., wind and groundwater -- that may transport the harmful constituents to

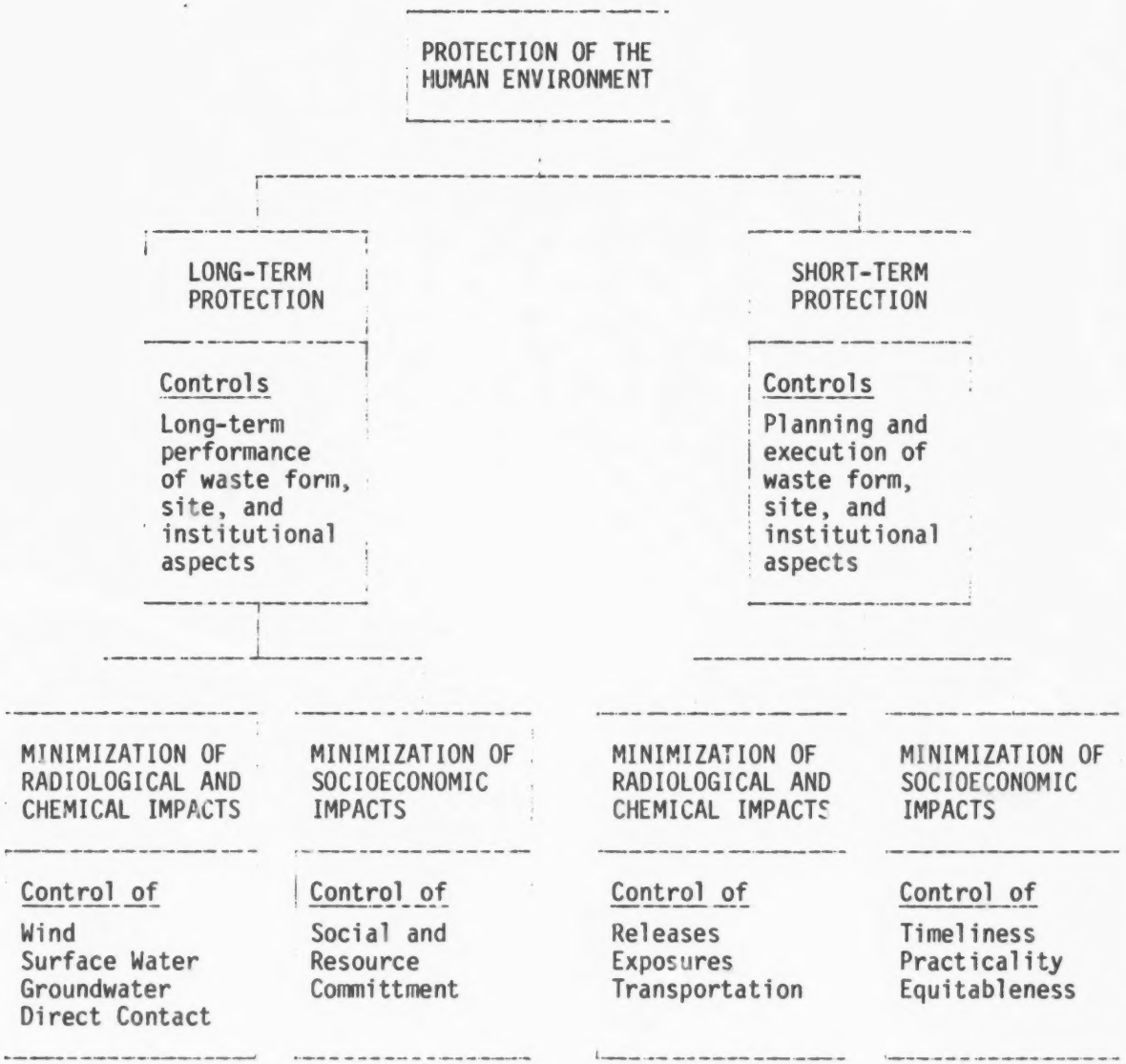

Figure 5.1 . Overview of Disposal Principles

the human environment. These barriers can be physical, such as site selection factors (distance to groundwater, low flooding potential, etc.), site design factors (special disposal cell covers, etc.), or site operational factors (waste emplacement procedures, operational drainage systems, etc.). The barriers can also be chemical such as waste form factors (solidification, incineration, etc.), or they can be administrative such as institutional barriers (land ownership, restricted land use, funding, etc.).

In order to minimize the long-term socioeconomic impacts, these controls should be applied to minimize the duration of the social committment -- e.g., extended care and maintenance -- and to minimize the committed resources. This can best be accomplished through ensuring that (1) the above barriers retain their design capability through the long term, and (2) the long-term performance of these barriers can be confidently predicted. An essential requirement in the protection of the human environment is the long-term stability and predictability of the disposal system. Instability and unpredictability almost invariably tend to increase long-term social commitment.

The short-term protection of the human environment can also be accomplished through good planning and proper execution of waste form, disposal site, and institutional controls. Short-term radiological and chemical impacts may be minimized by controlling such things as operational releases, occupational exposures, and transportation exposures.

In order to minimize socioeconomic impacts, it is necessary to have a disposal system that is timely (implementable in a timely manner), practical (simple and workable), and equitable (cost-effective). It is essential that while the disposal system must allow for future technological innovations, dependence on future innovations for good performance should be avoided.

5.2 Discussion

The authors believe that the most important shortcoming of early disposal practices has been a lack of sufficient consideration of the long-term protection of the human environment from radiological and (principally) economic impacts prior to the establishment of the disposal sites.

A frequently cited reason for the unanticipated economic impacts experienced at the closed disposal facilities is the fact that the facilities were closed prematurely, before a viable closure fund could be established. This argument points out that if the sites had continued operation, the disposal charges on the wastes disposed in later years could have been adjusted upward to take care of any difficulties. Experience gained in the interim would have permitted closure of the sites in accordance with whatever criteria necessary to protect the health and safety of the public, and the accumulation of whatever funds required for the extended care of the site.

There is validity in this argument, but it must be viewed with caution. It places regulators in a difficult position, and overall it is believed to be preferable to try to sufficiently plan for the long-term radiological and economic protection of the human environment prior to the establishment of a disposal site. While a particular disposal technology should be capable of accommodating future technological improvements, it must not be dependent upon such improvements. By their nature, remedial activities performed on earlier disposal areas take place after funds had been received for waste disposed in these areas. Such remedial activities therefore present an economic drain on current operations, and there has been a reluctance to perform these activities until a significant problem had arisen. In addition, the costs for such remedial activities, whether in the form of increased disposal charges or expenses by the State or Federal government, are eventually borne by society. It appears to be more equitable to impose whatever costs are required to safely dispose

of waste on the society actually generating the waste, rather than passing the costs on to future societies.

A more detailed discussion of the three principal controlling mechanisms for protection of the human environment -- i.e., waste form, site performance, and institutional controls -- is presented below.

Waste Form

The predictability of the long-term performance of the wastes and their compatability with site design has not been fully considered. For example, it is certain that the trench leachate accumulation problem (resulting to a certain extent from interflow but mostly from infiltrating precipitation) experienced at several of the sites would have been of much lesser significance if the structural instability of many of the waste forms had been fully taken into account.

Subsidence from decomposing and/or compressible wastes has been observed at a number of commercial and government sites. The worst aspect of the subsidence problem is its unpredictability. At several sites, it is expected that cardboard and wooden boxes containing structurally unstable wastes will decompose and/or compress and result in subsidence within five years after disposal. However, it is very difficult to predict when the subsidence caused by collapse of corroded metal drums or liners will occur. (Test programs have been carried out at INEL and SRP, for example, to exhume and examine previously disposed waste. The condition of the exhumed wastes have been extremely variable.) In addition, improved surface management practices such as improved emplacement and trench compaction techniques during and immediately after disposal cannot necessarily provide a guarantee against subsidence.

Clearly, if the trench subsidence problems had been anticipated and compensated for by direct (such as not disposing any compressible wastes) or indirect means (such as assuring that the trench cover will

retain its integrity despite waste compression), the trench covers at several of the sites could have provided effective protection against percolating rainwater. For example, West Valley, New York soils are mostly low-permeability clayey tills which would have provided an excellent low-permeability cover if the integrity of the cover could have been assured by protecting it against external (weather effects) and internal (waste compression) forces.

Furthermore, it has always been standard practice in the past to dispose of wastes as they arrived at the site with only minor consideration being given to the fundamental differences in their characteristics. The external radiation level of the waste package was the only characteristic consistently taken into account in the past. Other differences in physical, chemical, and radiological characteristics such as compactability, complexing chemical agent content, and radiotoxicity (e.g., TRU radionuclides vs tritium), when properly taken into account (e.g., segregation), can enhance the confinement capability of a disposal site significantly.

Site Performance

The second aspect of the disposal technology which has been given insufficient consideration in the past is the long-term performance of the site. This aspect can roughly be considered in three parts: site selection, site design, and site operations.

In the past, the most influential consideration for locating many disposal sites has been the availability of land, rather than the natural characteristics of the sites which would enhance the confinement capability of the disposal technology. Although some consideration was given to some of the site characteristics (e.g., more recent ORNL disposal areas are located in Melton Valley with shaley soils rather than in Bethel Valley with limestone features and fractures), frequently the impact of the natural forces on the disposed wastes were not fully considered.

The effects of disposal system interaction with surface hydrologic regimes (e.g., floods), in-situ permeability of the disposed wastes when compared to the adjacent undisturbed soil permeabilities, and the complexity of the underlying soils and geology are issues that must be considered in the optimization of the confinement capability of a disposal technology. For example, Maxey Flats has had difficulties resulting from the siting within horizons containing fractured sandstone, and sheet and gully erosion problems have been experienced at several sites including Maxey Flats, Sheffield, and West Valley. All these site features which were not fully taken into account during the siting and operation of the facilities have resulted in unpredictability of long-term offsite impacts.

Moreover, the designs of the past disposal sites often did not fully consider the long-term implications of natural environmental forces (e.g., precipitation, surface water drainage, wind or water erosion) on the disposed wastes. For example, surface erosion has been experienced or is a concern at some sites and there have been occasions when wastes were disposed either directly into saturated ground below the water table or were disposed so that they were inundated during annual cycles of rising groundwater. In addition, two of the three commercial sites which are now closed (West Valley and Maxey Flats) have experienced significant leachate accumulation problems and their closure in large part can be directly attributed to this leachate accumulation. Some of the ORNL disposal areas have also experienced leachate accumulation problems. In all cases, high annual precipitation rates combined with low permeability of in-situ undisturbed soils and relatively higher permeability trench covers have resulted in the accumulation of significant volumes of leachate. This condition is frequently referred to as the "bathtub" effect.

In the "bathtub" effect scenario, precipitation that does not evaporate, or is not transpirated by vegetation, or does not become part of the surface runoff component, often infiltrates into the waste disposal cell. As a result of the relatively low permeability of the

undisturbed (unexcavated) surrounding soils, the rate of lateral and vertical movement is significantly lower than the permeability of the (disturbed) trench cover material. The waste cell then fills up at a rate depending on the infiltration rate of water. If the infiltration rate is significantly greater than the rate of lateral or vertical drainage, water can accumulate in the disposal trenches and possibly overflow the trenches. At ORNL, the bathtub problem was compounded in some cases by constructing lengthy trenches lengthwise to sloping ground so that one end of the trench was significantly higher than the other end. This produced a driving mechanism for subsequent surface seepage of contaminated water. To avoid an uncontrolled release through trench overflow, leachate accumulating in West Valley and Maxey Flats trenches has been pumped out and treated. The additional care requirements resulting from the bathtub effect are often unpredictable and can result in significant expenditures of resources and consequently, increase the long-term care funding requirements.

The augmentation of the infiltration potential at any site can appreciably increase the potential for and rate of leachate accumulation at a disposal site. The augmentation of the infiltration potential can result from poor trench cover compaction, insufficient cover thickness (low moisture storage capacity) or vegetative cover, trench cover cracking, trench cover collapse, and poor surface drainage.

The third site-related shortcoming of the past disposal practices has been in the area of site operational procedures. Insufficient consideration has been given to operational practices that could adversely influence the long-term confinement capability of the disposal system. These events include closing a disposal trench with standing water, installing trench covers which do not adequately exclude precipitation or other elements (vegetation, animals or humans), and unplanned surface contamination events which reduces environmental monitoring capability.

Institutional Aspects

The long-term reliability and/or performance of the institutional requirements is the third controlling mechanism for which insufficient consideration was given. Unlike other types of facilities, the function of a disposal facility really begins after it is "decommissioned." The uncertainties as to the future status of several of the existing disposal sites with regard to finances, ownership, maintenance, etc. have resulted in a crisis of confidence and predictability.

At two closed commercial facilities (Maxey Flats and West Valley), a substantial committment of resources (effort and money) has been necessary to prevent unplanned releases of radioactivity. At a third site (Sheffield), continual maintenance is likely to be required for several years to reduce potential releases to levels as low as reasonably achievable. Costly remedial programs have also been carried out at several government sites. In all cases, past releases have not resulted in significant endangerment of the public health and safety. However, this committment of resources was neither planned nor predicted, and has led to the erosion of public confidence in safe and predictable LLW disposal.

5.3 Summary

Both physical and institutional predictability and stability of the disposal system are essential for determining the long-term requirements. Insufficient consideration was given to the long-term stability and the behavior of the waste after emplacement, the stability and performance of the disposal design, and the predictability and adequacy of the institutional requirements. Site selection and licensing of commercial disposal sites were often performed on an ad-hoc basis to provide locally-needed disposal capacity or in hope of attracting other types of nuclear industries to a particular area. The lack of regulatory standards and requirements against which the

performance of current and future disposal sites can be uniformly evaluated was an important contributing factor to the existing crisis management atmosphere.

One of the consequences of the lack of sufficient consideration for the long-term protection of the human environment has been the refrain that insufficient environmental data exists on the existing disposal facilities to determine long-term environmental effects. If proper consideration and control of the long-term implications of waste form, site and institutional aspects are made, and the sites are selected and designed accordingly, this would likely not be the case in the future.

APPENDIX A

SUMMARY OF VOLUMES AND ACTIVITIES OF GOVERNMENT AND COMMERCIAL LLW

APPENDIX A : SUMMARY OF VOLUMES AND ACTIVITIES OF GOVERNMENT AND COMMERCIAL LLW

This appendix presents a summary of the volumes and activities of wastes disposed at the principal sites operated by the Federal government, as well as those sites operated by private industry.

Table A-1 summarizes the volumes and activities of solid waste accumulated at Department of Energy (DOE) sites through the year 1979. Table A-2 lists the volumes and activities of wastes for just the year 1979. Tables A-3 and A-4 list volumes and activities of DOE waste summarized by DOE operational region.

Listed are wastes from the five principal DOE facilities, including Los Alamos Scientific Laboratory (LASL), Idaho National Engineering Laboratory (INEL), the Hanford Reservation (HR), Oak Ridge National Laboratory (ORNL), and the Savannah River Plant (SRP). Also shown are volumes and activities of waste accumulated at the Nevada Test Site (NTS) as well as volumes and activities of waste summed over several other minor sites. In the tables, transuranic (TRU) wastes are retrievably stored while the other wastes are disposed.

Tables A-5 through A-9 list volumes and quantities of wastes disposed at the six commercial disposal facilities for each year from 1963 through the year 1980. Total accumulated volumes and quantities are also shown. The six commercial facilities include those located near Beatty, Nevada, Maxey Flats, Kentucky, Richland, Washington, West Valley, New York, and Barnwell, South Carolina. Waste volumes are listed in Table A-5, while the quantities of byproduct material (in curies), source material (in pounds), and special nuclear material (in kilograms) are listed in Tables A-6 through A-8. Finally, the amounts of plutonium (in kilograms) disposed at the commercial disposal sites are listed in Table A-9.

For these tables, byproduct material is defined in the NRC regulation 10 CFR Part 20 as "any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material."

Similarly, source material is defined as "(i) uranium or thorium, or any combination thereof, in any physical or chemical form, or (ii) ores which contain by weight one-twentieth of one percent (0.05%) or more of (a) uranium, (b) thorium, or (c) any combination thereof. Source material does not include special nuclear material."

Special nuclear material is defined as "(i) plutonium uranium-233, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the Commission, pursuant to the provisions of section 51 of the Act [The Atomic Energy Act of 1954, plus any amendments thereof], determines to be special nuclear material, but does not include source material, or (ii) any material artificially enriched by any of the foregoing but does not include source material."

TABLE A-1 : Accumulated Solid Waste at DOE Storage and Disposal Sites Through Fiscal Year 1979

DOE Site		Total	TRU	Uranium, Thorium	Fission Product	Induced Activity	Tritium	Beta-Gamma	Alpha	Other
LASL	Volume*	1.699E5	1.453E4	4.760E4	3.688E3	3.745E3	1.653E3	7.351E1	9.864E4	------
	Activity**		1.181E2	4.964E4	4.356E4	4.654E3	3.915E5	4.509E3	3.026E3	------
INEL/ RWMC	Volume	2.165E5	9.949E4	1.803E3	5.208E4	5.522E4	------	1.679E1	7.935E3	------
	Activity		2.204E5	6.777E4	2.853E6	5.481E6	------	2.441E2	1.243E3	------
NTS	Volume	5.721E4	2.432E2	8.387E3	2.911E4	4.138E3	4.171E1	1.100E1	1.518E4	9.792E1
	Activity		1.666E0	8.818E3	2.904E3	9.544E1	4.845E6	4.862E-3	5.253E0	1.326E3
HR	Volume	6.592E4	8.038E3	------	4.816E4	9.717E3	------	8.438E-1	------	------
	Activity	------	3.016E4	------	1.011E5	1.261E6	------	1.220E1	------	------
ORNL	Volume	1.924E5	3.843E2	4.567E2	4.067E3	1.828E3	6.963E1	7.895E2	3.251E2	1.844E5
	Activity		8.124E1	1.382E4	6.099E4	7.637E3	1.668E3	1.623E4	9.170E1	4.220E5
SRP	Volume	3.389E5	2.365E3	4.461E4	2.017E5	4.736E4	1.270E4	2.581E3	2.727E4	3.686E2
	Activity		5.253E1	4.611E2	7.369E5	1.723E8	3.906E6	6.090E2	5.021E3	1.823E5
Other Sites	Volume	8.449E5	4.003E1	4.359E5	6.049E3	8.776E4	4.245E2	3.144E5	2.762E1	3.213E2
	Activity		2.204E2	1.583E7	9.776E5	1.212E5	1.653E3	1.096E6	9.066E1	3.853E0
TOTAL DOE	Volume	1.886E6	1.251E5	5.387E5	3.448E5	2.098E5	1.489E4	3.178E5	1.494E5	1.852E5
	Activity		2.511E5	1.597E7	4.776E6	1.792E8	9.146E6	1.118E6	9.388E3	6.056E5

* Volume in m^3; exponential notation, 1.699E5 = 1.699×10^5.
** Activity in Curies, except for TRU and Uranium/Thorium columns which are given in kilograms.
Note: No entry in a column indicates no data reported.

Source: Reference 1 (Reports 034 and 049).

TABLE A-2 : Solid Waste Added at DOE Storage and Disposal Sites for Fiscal Year 1979

DOE Site		Total	TRU	Uranium, Thorium	Fission Product	Induced Activity	Tritium	Beta-Gamma	Alpha	Other
LASL	Volume*	5.940E3	1.191E3	8.466E2	7.575E1	3.495E2	2.103E2	7.750E0	3.258E3	------
	Activity**		3.088E1	9.696E3	3.002E4	3.642E1	8.837E4	1.656E2	1.137E3	------
INEL/ RWMC	Volume	6.605E3	1.093E3	1.388E1	1.550E3	3.943E3	------	5.612E0	------	------
	Activity		1.949E1	2.444E2	2.599E4	1.164E6	------	1.535E2	------	------
NTS	Volume	3.376E4	4.181E1	6.953E3	1.564E4	9.159E0	1.392E1	1.100E1	1.099E4	8.962E1
	Activity		2.310E-2	4.680E3	2.479E1	2.102E0	4.498E5	4.862E-3	2.759E0	9.462E2
HR	Volume	1.142E4	5.831E2	------	8.904E3	1.935E3	------	------	-------	-------
	Activity		1.184E3	------	4.897E4	1.982E5	------	------	-------	-------
ORNL	Volume	1.993E3	3.273E1	1.737E2	8.939E2	4.382E2	3.729E1	4.253E1	2.478E2	1.271E2
	Activity		8.171E-1	1.327E4	5.432E4	4.529E2	5.602E2	1.971E2	7.735E1	7.547E0
SRP	Volume	1.902E4	2.158E2	2.361E3	1.011E4	3.008E3	1.398E3	1.756E2	1.610E3	1.358E2
	Activity		3.354E0	1.494E1	1.041E3	2.321E5	6.634E4	7.200E1	3.329E0	1.044E0
Other Sites	Volume	7.576E3	------	4.939E3	2.609E3	1.220E1	1.123E1	2.088E0	2.955E0	5.663E-2
	Activity		------	8.592E5	4.597E5	2.894E4	2.656E1	2.273E4	6.664E-1	3.136E0
TOTAL DOE	Volume	8.631E4	3.158E3	1.529E4	3.979E4	9.694E3	1.670E3	2.445E2	1.612E4	3.525E2
	Activity		1.239E3	8.871E5	6.300E5	1.623E6	6.051E5	2.332E4	1.221E3	9.579E2

* Volume in m^3; exponential notation, 5.94E3 = 5.94×10^3.
** Activity in Curies, except for TRU and Uranium/Thorium columns which are given in kilograms.
Note: No entry in a column indicates no data reported.

Source: Reference 1 (Reports 036 and 047).

TABLE A-3 . Accumulated Solid Waste Generated by DOE Operational Regions Through Fiscal Year 1979

Region	Total	TRU	Uranium, Thorium	Fission Product	Induced Activity	Tritium	Beta-Gamma	Alpha	Other
Albuequerque									
Volume*	1.714E5	1.457E4	4.791E4	3.814E3	4.394E3	2.008E3	7.351E1	9.867E4	5.663E-2
Activity**		1.205E2	7.640E4	4.409E4	9.754E3	3.931E5	4.509E3	3.027E3	3.136E0
San Francisco									
Volume	8.487E3	------	8.480E3	3.700E0	3.400E0	------	------	------	------
Activity		------	3.631E4	4.354E-3	1.431E-2	------	------	------	------
Chicago									
Volume	8.445E2	----	2.832E-2	1.468E0	4.497E2	6.986E1	2.196E0	------	3.213E2
Activity		----	5.340E0	5.595E2	7.958E4	2.789E0	2.598E4	------	7.172E-1
Idaho									
Volume	2.165E5	9.949E4	1.803E3	5.208E4	5.522E4	------	1.679E1	7.935E3	------
Activity		2.204E5	6.777E4	2.853E6	5.481E6	------	2.441E2	1.243E3	------
Nevada									
Volume	5.726E4	2.432E2	8.387E3	2.916E4	4.138E3	4.171E1	1.100E1	1.518E4	9.792E1
Activity		1.666E0	8.818E3	2.936E3	9.544E1	4.845E6	4.862E-3	5.253E0	1.326E3
Oak Ridge									
Volume	6.194E5	3.869E2	4.275E5	4.067E3	1.828E3	6.973E1	7.895E2	3.251E2	1.844E5
Activity		2.985E2	1.578E7	6.099E4	7.637E3	1.669E3	1.623E4	9.170E1	4.220E5
Richland									
Volume	4.728E5	8.039E3	-------	5.403E4	9.638E4	------	3.144E5	------	------
Activity		3.017E4	-------	1.078E6	1.298E6	------	1.070E6	------	------
Savannah River									
Volume	3.389E5	2.365E3	4.461E4	2.017E5	4.736E4	1.270E4	2.581E3	2.727E4	3.686E2
Activity		5.253E1	4.611E2	7.369E5	1.723E8	3.906E6	6.090E2	5.021E3	1.823E5

* Volume in m^3; exponential notation, 1.714E5 = 1.714×10^5.
** Activity in Curies, except for TRU and Uranium/Thorium columns which are given in kilograms.
Note: No entry in a column indicates no data reported.

Source: Reference 1 (Reports 034 and 049)

TABLE A-4 : Solid Waste Generated by DOE Operational Regions for Fiscal Year 1979

Region	Total	TRU	Uranium, Thorium	Fission Product	Induced Activity	Tritium	Beta-Gamma	Alpha	Other
Albuequerque									
Volume*	5.992E3	1.191E3	8.688E2	8.022E1	3.611E2	2.215E2	7.750E0	3.261E3	5.663E-2
Activity**		3.088E1	1.174E4	3.002E4	1.235E2	8.840E4	1.656E2	1.138E3	3.136E0
San Francisco									
Volume	1.408E3	------	1.408E3	------	------	-------	-------	-------	-------
Activity		------	2.173E2	------	------	-------	-------	-------	-------
Chicago									
Volume	1.240E0	------	------	2.216E-1	6.164E-1	-------	4.016E-1	-------	-------
Activity		------	------	1.600E1	2.885E4	-------	2.095E4	-------	-------
Idaho									
Volume	6.605E3	1.093E3	1.388E1	1.550E3	3.943E3	-------	5.612E0	-------	-------
Activity		1.949E1	2.444E2	2.599E4	1.164E6	-------	1.535E2	-------	-------
Nevada									
Volume	3.376E4	4.181E1	6.953E3	1.564E4	9.159E0	1.392E1	1.100E1	1.100E4	8.962E1
Activity		2.310E-2	4.680E3	3.030E1	2.102E0	4.498E5	4.862E-3	2.759E0	9.462E2
Oak Ridge									
Volume	5.502E3	3.273E1	3.682E3	8.939E2	4.382E2	3.729E1	4.253E1	2.478E2	1.271E2
Activity		8.171E-1	8.702E5	5.432E4	4.529E2	5.602E2	1.971E2	7.735E1	7.547E0
Richland									
Volume	1.403E4	5.831E2	------	1.151E4	1.935E3	-------	1.687E0	-------	-------
Activity		1.184E3	------	5.186E5	1.982E5	-------	1.776E3	-------	-------
Savannah River									
Volume	1.902E4	2.158E2	2.361E3	1.011E4	3.008E3	1.398E3	1.756E2	1.610E3	1.358E2
Activity		3.354E0	1.494E1	1.041E3	2.321E5	6.634E4	7.200E1	3.329E0	1.044E0

* Volume in m^3; exponential notation, 5.992E3 = 5.992×10^3.
** Activity in Curies except for TRU, and Uranium/Thorium columns which are given in kilograms.
Note: No entry in a column indicates no data reported.

Source: Reference 1 (Reports 037 and 048).

TABLE A-5 : Volumes of Disposed Commercial Low-level Radioactive Wastes (million ft^3)

Year	BEATTY	MAXEY FLATS	RICHLAND	SHEFFIELD	WEST VALLEY	BARNWELL	ANNUAL TOTAL	CUMULATIVE TOTAL
1963	0.1380	0.0779			0.0045		0.2204	0.2204
1964	0.0994	0.1372			0.2681		0.5047	0.7251
1965	0.0847	0.2032	0.0228		0.2360		0.5467	1.2718
1966	0.1518	0.1962	0.0841		0.1456		0.5777	1.8495
1967	0.1183	0.2762	0.0273	0.0886	0.2694		0.7798	2.6293
1968	0.1358	0.2888	0.0480	0.0964	0.1367		0.7057	3.3350
1969	0.1599	0.3656	0.0154	0.0711	0.1369		0.7489	4.0839
1970	0.1819	0.6301	0.0242	0.0998	0.1224		1.0584	5.1423
1971	0.1736	0.4651	0.0206	0.1565	0.2391	0.0496	1.1045	6.2468
1972	0.1329	0.5501	0.0284	0.2163	0.2672	0.1455	1.3404	7.5872
1973	0.1368	0.3567	0.0366	0.3041	0.2648	0.6139	1.7129	9.3001
1974	0.1449	0.1246	0.0498	0.4370	0.2028	0.6363	1.5954	10.8955
1975	0.1745	0.6038	0.0530	0.5000	0.0667	0.6582	2.0562	12.9517
1976	0.1364	0.4864	0.1014	0.4760		1.4204	2.6206	15.5723
1977	0.193	0.0081	0.0684	0.6232		1.516	2.4087	17.9810
1978	0.31		0.29	0.1274		2.23	2.9574	20.9384
1979	0.26		0.43			2.255	2.9450	23.8834
1980	0.45		0.88			1.900	3.2300	27.1134
Totals	3.1819	4.7700	2.1800	3.1960	2.3602	11.4249		

Source : Reference 2.

TABLE A-6 : Activity of Byproduct Material Disposed at the Commercial LLW Sites (million curies)

Year	BEATTY	MAXEY FLATS	RICHLAND	SHEFFIELD	WEST VALLEY	BARNWELL	ANNUAL TOTAL	CUMULATIVE TOTAL
1963	0.0054	0.0266			0.0013		0.0333	0.0333
1964	0.0062	0.1483			0.0114		0.1659	0.1992
1965	0.0075	0.0638	0.0001		0.0215		0.0929	0.2921
1966	0.0140	0.0527	0.0007		0.0410		0.1084	0.4005
1967	0.0110	0.0423	0.0053	0.0047	0.0512		0.1145	0.5150
1968	0.0112	0.0456	0.0679	0.0015	0.0517		0.1779	0.6929
1969	0.0098	0.0310	0.0603	0.0022	0.0233		0.1266	0.8195
1970	0.0073	0.0642	0.0528	0.0054	0.0363		0.1660	0.9855
1971	0.0040	0.7201	0.0238	0.0079	0.0424	0.0042	0.8024	1.7879
1972	0.0049	0.2174	0.0318	0.0049	0.0612	0.0092	0.3294	2.1173
1973	0.0039	0.0668	0.0617	0.0028	0.1706	0.2079	0.5137	2.6310
1974	0.0239	0.1466	0.0122	0.0032	0.0555	0.0140	0.2554	2.8864
1975	0.0184	0.2898	0.0059	0.0061	0.1326	0.0179	0.4707	3.3571
1976	0.0045	0.2114	0.1043	0.0077		0.0902	0.4181	3.7752
1977	0.024	0.2740	0.0076	0.0111		0.2146	0.5313	4.3065
1978	0.0056		0.2206	0.0025		0.6521	0.8808	5.1873
1979	0.0089		0.264			0.315	0.5879	5.7752
1980	0.150		0.037			0.140	0.3270	6.1022
Totals	0.3205	2.4006	0.9560	0.0602	0.7000	1.6651		

Source : Reference 2.

TABLE A-7 : Source Material Disposed at the Commercial LLW Sites (Million pounds)

Year	BEATTY	MAXEY FLATS	RICHLAND	SHEFFIELD	WEST VALLEY	BARNWELL	ANNUAL TOTAL	CUMULATIVE TOTAL
1963	0.0038	0.0114			0.0167		0.0319	0.0319
1964	0.0029	0.0123			0.0222		0.0374	0.0693
1965	0.0017	0.0012			0.0489		0.0518	0.1211
1966	0.0058	0.0011	0.0051		0.0843		0.0963	0.2174
1967	0.0008	0.0125		0.0089	0.0446		0.0668	0.2842
1968	0.0028	0.0138		0.0217	0.0142		0.0525	0.3367
1969	0.0008	0.0056	0.0005	0.0140	0.1760		0.1969	0.5336
1970	0.0007	0.0189	0.0005	0.0044	0.0698		0.0943	0.6279
1971	0.009	0.0127	0.0035	0.0005	0.1132	0.0277	0.1666	0.7945
1972	0.0206	0.0182	0.0148	0.0079	0.1669	0.0350	0.2634	1.0579
1973	0.0243	0.0243	0.0110	0.0053	0.0974	0.0855	0.2478	1.3057
1974	0.0414	0.0289		0.0307	0.1360	0.0459	0.2829	1.5886
1975	0.0032	0.1819	0.0334	0.0862	0.0358	0.0889	0.4294	2.0180
1976	0.0110	0.1674	0.0111	0.0085		0.0537	0.2517	2.2697
1977	0.0223	0.0228	0.0061	0.4071		0.3953	0.8536	3.1233
1978	0.1708		0.0130	0.0047		1.7724	1.9609	5.0842
1979	0.289		0.0285			2.693	3.0105	8.0947
1980	0.190		0.014			0.450	0.6540	8.7487
Totals	0.8009	0.5330	0.1415	0.5999	1.0260	5.6474		

Source: Reference 2.

TABLE A-8 : Special Nuclear Material Disposed at the Commercial LLW Sites (Kilograms)

Year	BEATTY	MAXEY FLATS	RICHLAND	SHEFFIELD	WEST VALLEY	BARNWELL	ANNUAL TOTAL	CUMULATIVE TOTAL
1963	3.59	0.79					4.38	4.38
1964	7.00	11.89			5.89		24.78	29.16
1965	11.98	4.26			3.09		19.33	48.49
1966	10.15	7.46	1.41		5.06		24.08	72.57
1967	25.29	14.84		1.20	2.28		43.61	116.18
1968	8.80	17.77		2.29	2.21		31.07	147.25
1969	6.22	31.50	0.03	3.84	5.03		46.62	193.87
1970	9.31	47.57	0.21	5.95	8.24		71.28	265.15
1971	20.06	72.77	0.02	9.94	4.95	20.36	128.10	393.25
1972	20.93	71.44	0.64	5.90	7.32	60.97	167.20	560.45
1973	6.52	46.23	7.05	6.13	7.70	85.81	159.44	719.89
1974	16.95	22.72	4.88	6.18	2.99	98.74	152.46	872.35
1975	31.28	25.69	18.98	5.29	1.24	76.98	159.46	1031.81
1976	2.10	27.47	24.38	1.74		0.11	55.80	1087.61
1977	11.29	29.22	36.14	5.31		310.03	391.99	1479.60
1978	7.67		19.80	2.13		220.90	250.50	1730.10
1979	4.77		7.89			7.89	20.55	1750.65
1980	13.6					239.00	252.60	2003.35
Totals	217.51	431.62	121.43	55.90	56.00	1120.79		

Source : Reference 2.

TABLE A-9 . Plutonium Disposed at the Commercial LLW Sites (Kilograms)

Year	BEATTY	MAXEY FLATS	RICHLAND	SHEFFIELD	WEST VALLEY	BARNWELL	ANNUAL TOTAL	CUMULATIVE TOTAL
1963		0.67					0.67	0.67
1964	0.06	6.95			0.02		7.03	7.70
1965	0.19	2.60			0.41		3.20	10.90
1966	0.33	0.76	0.06		0.34		1.49	12.39
1967	0.66	2.43			0.33		3.42	15.81
1968	0.30	5.54			0.27		6.11	21.92
1969		4.32	0.01	0.03			4.36	26.28
1970	0.95	3.77	0.03	2.76			7.51	33.79
1971	1.11	8.70	0.01	5.43	1.21		16.46	50.25
1972	0.78	23.87	0.30	2.16	0.50		27.61	77.86
1973	0.48	1.24	0.14	1.85	0.52		4.23	82.09
1974		1.13	0.80	0.97			2.90	84.99
1975	9.43	0.10	11.36	0.21	0.40		21.50	106.49
1976			9.97				9.97	116.46
1977		1.68	8.02				9.70	126.16
1978			4.92				4.92	131.08
1979			0.905				0.905	131.985
Total	14.29	63.76	36.525	13.41	4.00	0		

Source : Reference 2.

REFERENCES FOR APPENDIX A

(1) U. S. Department of Energy, "Solid Waste Information Management Systems," U.S. DOE-SWIMS-1980.

(2) Personal Communication from G. Roles, Low-Level Waste Licensing Branch, U. S. Nuclear Regulatory Commission, to J. Clancy, Dames and Moore, Inc., March 18, 1980.

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16. ABSTRACT (200 words or less)

This document is prepared in three volumes and provides part of the technical support to the draft environmental impact statement (NUREG-0782) on a proposed regulation, 10CFR Part 61, setting forth licensing requirements for land disposal of low level radioactive waste. Volume 1 is a summary and analysis of the history of low level waste disposal at both commercial and government disposal facilities. Volume 2 provides a summary of low level waste volumes and characteristics as projected to the year 2000, in addition to characterizing treatment options for this waste. Volume 3 provides a methodology for analyzing the impacts of handling and disposing of low level waste based upon consideration of alternative waste forms, disposal facility design and operating practices, disposal facility environmental characteristics, and institutional control considerations.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

low-level waste
land disposal
social commitment
ground water migration
inadvertent intrusion
10 CFR Part 61
waste form
waste packaging
waste volumes
institutional controls
radioactive waste
disposal technologies
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disposal sites

17b. IDENTIFIERS/OPEN-ENDED TERMS

18 AVAILABILITY STATEMENT Unlimited	19 SECURITY CLASS (This report) Unclassified	21 NO OF PAGES
	20 SECURITY CLASS (This page) Unclassified	22 PRICE S

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